BRITISH WELDING JOURNAL

1958 OCTOBER

VOL. 5 NO. 10

CONTENTS

Positioners for Automatic Welding
By W. A. Davis

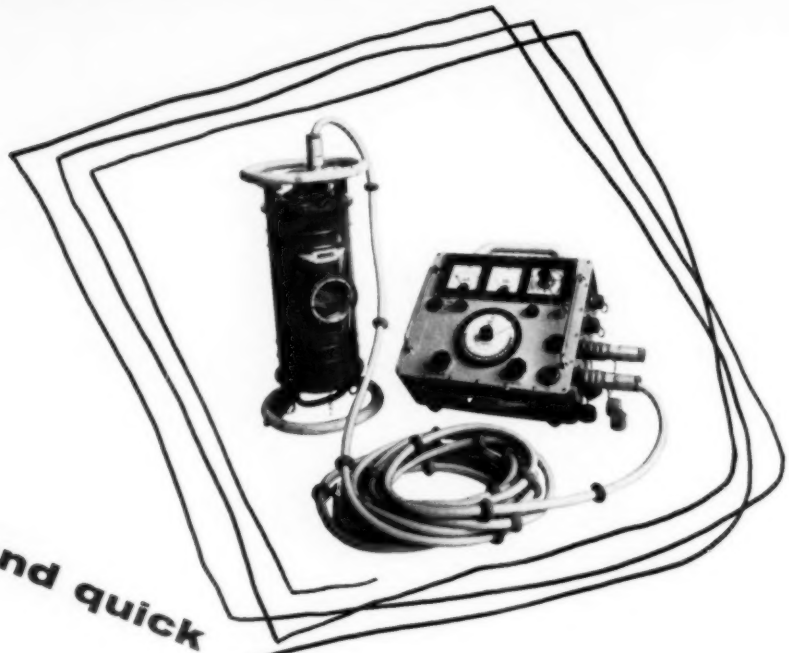
Metal-Arc Welding of Aluminium Bronze
By M. K. Williams and W. I. Pumphrey

Developments in Arc Welding Processes
By P. Shaw and D. B. Tait

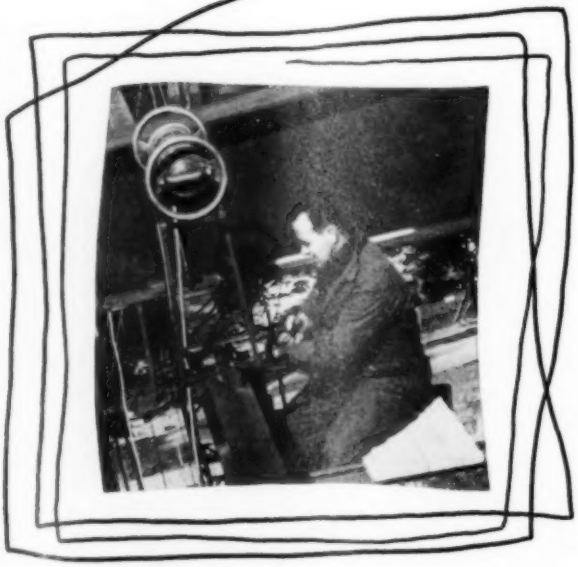
Welding of Creep Resisting Steels
By J. F. Mercer

Self-Guided Welding of Aluminium
By J. E. Tomlinson and R. V. Blewett

Welding Dissimilar Alloy Steels
By M. C. T. Bystram



easy and quick 'on the spot' inspections



with the

PORTABLE ANDREX 160 kVp unit

Easy handling, quick set up, and more radiographs per unit, make this portable light-weight unit in constant demand throughout the world. Powerful enough to go through 2" steel or 5" aluminium, the Andrex 160 weighs only 64 pounds — without sacrificing the lead protection. 40% lighter, and 30% smaller, than previous units of equal capacity, the Andrex 160 can pass through a 12" hole, and can be easily carried in one hand. For those *difficult* inspections use the portable 160 kVp unit.
Also available for panoramic exposures is the ANDREX 160 360° unit which is of the same low weight and small dimensions as the standard set.

The Portable ANDREX 160, ANDREX 130, the 130 Automatic, the 200 and the 260 kVp X-ray units are manufactured by

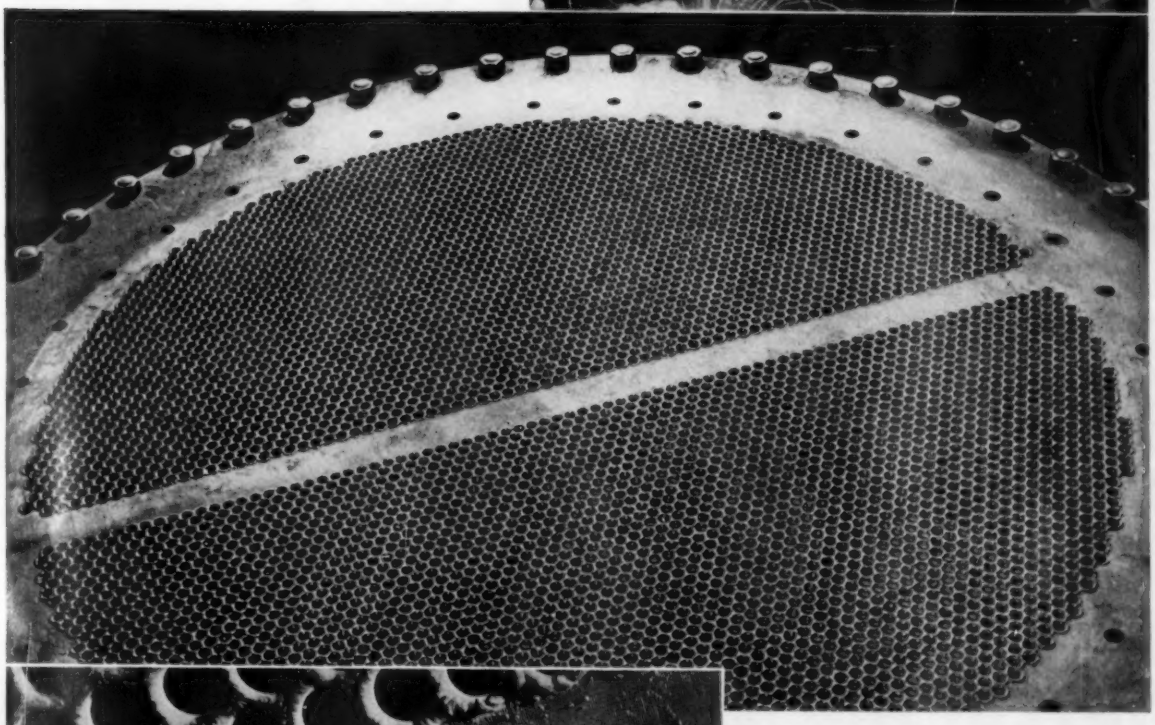
HOLGER ANDREASEN, Islands Brygge 41, Copenhagen S., Denmark.

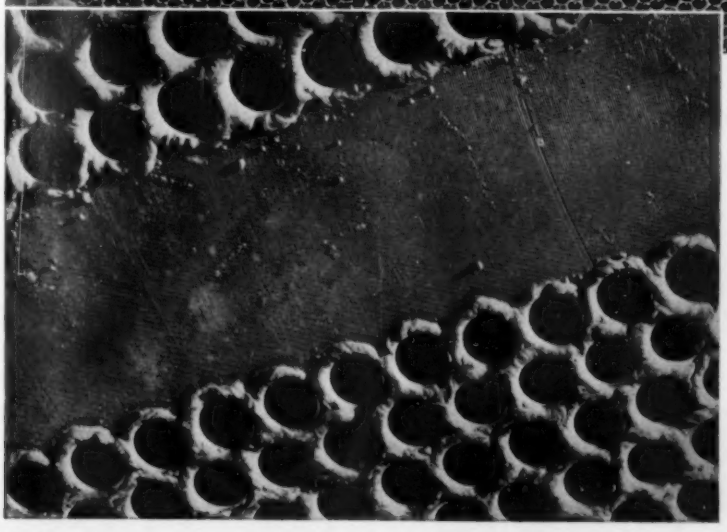
ANDREX

Sole U.K. Distributors: **B.I.X. LTD., HANOVER HOUSE, 73 HIGH HOLBORN, LONDON, W.C.1**

Inside front cover

Dexterity in WELDING





Tube plate for a Heat Exchanger, incorporating 5,518 tubes ¾ in. dia., and involving 1,078 footage of welding.

Harvey

G. A. HARVEY & CO. (LONDON) LTD
Woolwich Road.....London, S.E.7
Telephone: GREenwich 3232 (22 lines)

Specified by G.E.C.

ATOMIC ENERGY DIVISION

DIADEM

Opal Electrodes

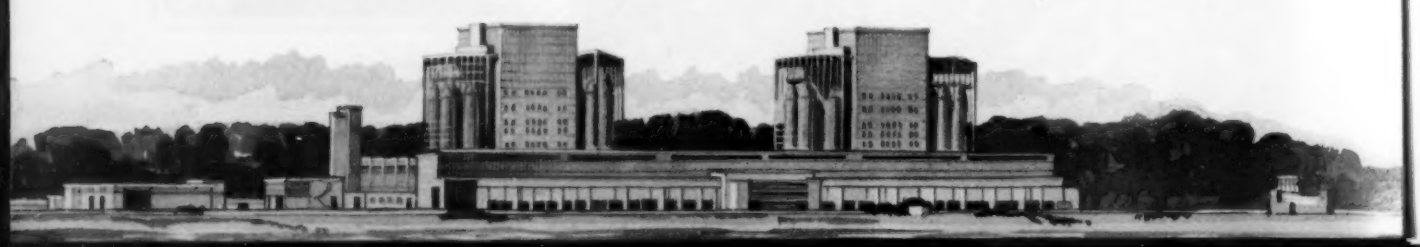
for

HUNTERSTON ATOMIC POWER STATION

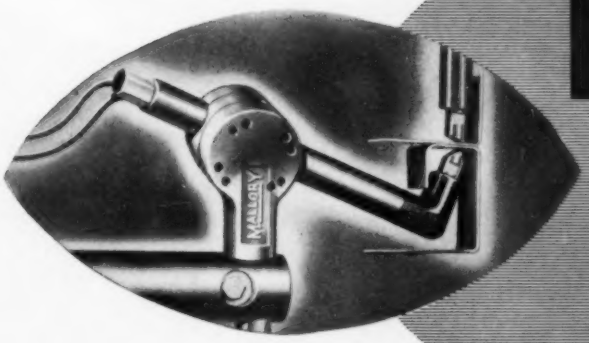
The special 3-inch thick notch-tough steel of the great Reactor Vessels are being butt welded on site exclusively with Diadem OPAL Electrodes, which are also being used for all ducting and steam raising units. At least 100 miles of OPAL Electrodes, weighing over 40 tons, will be used on this project. Hunterston Power Station is being built for the South of Scotland Electricity Board by the General Electric Co. Limited, in association with Simon Carves Limited, Motherwell Bridge and Engineering Co. Limited and John Mowlem & Co. Limited.

COOPER AND TURNER LTD.,
VULCAN WORKS, VULCAN ROAD, SHEFFIELD 9

Manufacturers of Rivets and Arc-Welding Electrodes
Telephone: 42091 Telegrams: Rivets, Sheffield



Standard tools for special jobs



. . . and, of course. for standard jobs, also. For the advantage of MALLORY standard spot welding electrodes, holders and adaptors, is that whether the work in hand is simple or full of awkward corners a set-up can usually be devised that will do the job – without the need for expensive special tools.

MALLORY standardisation is sensible tooling – and sensible economics.

Booklet 1200 "Mallory Resistance Welding" gives details of the Mallory range of standard welding equipment. Copies are free on request.

Johnson Matthey
MALLORY

JOHNSON, MATTHEY & CO., LIMITED
controlling MALLORY METALLURGICAL PRODUCTS LTD.

73-83 HATTON GARDEN, LONDON E.C.1
Telephone: Holborn 6989

Vittoria Street, Birmingham, 1. Telephone: Central 8004

75–79 Eyre Street. Sheffield, 1. Telephone: 29212

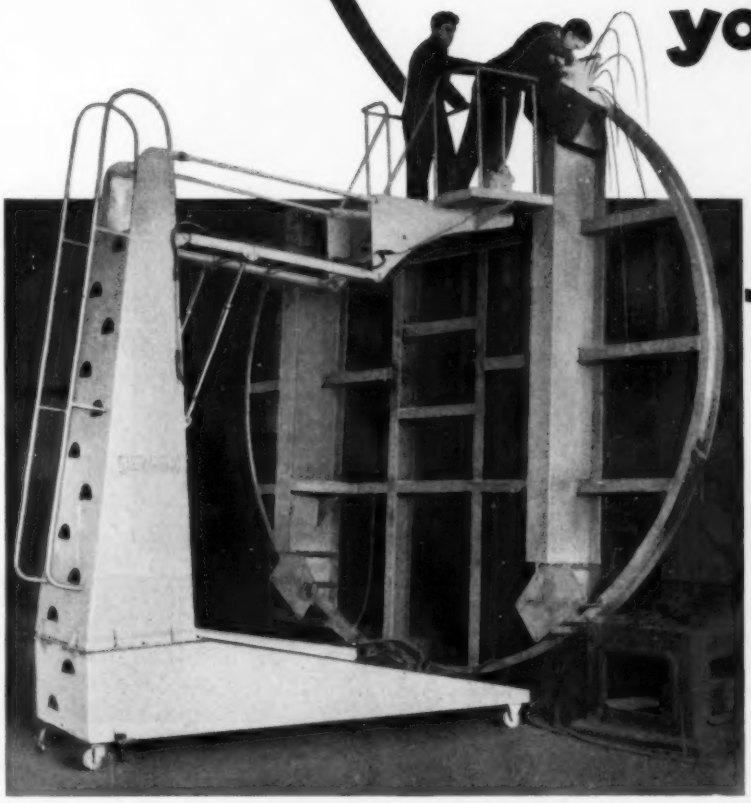
More than equal to the extra service demanded

PIRELLI-GENERAL CABLES

ORDER FROM THE G.E.C.

The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2

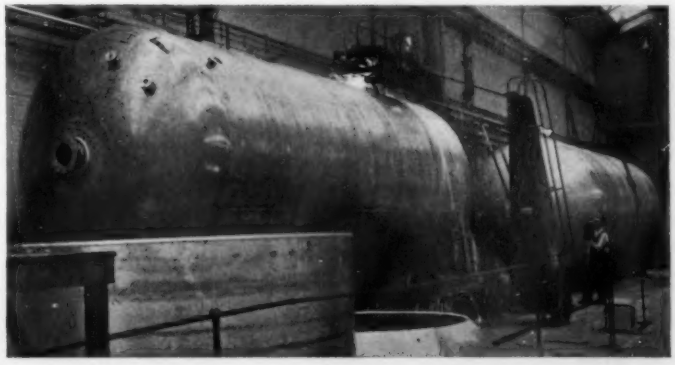
Anywhere you need to weld



. . . a COURTBURN OPERATOR'S PLATFORM is easily manœuvred into position within seconds. It meets the need for a robust mobile elevating platform to enable welders and other operators to have access to bulky work-pieces. It is particularly necessary when welding large boilers and other cylindrical vessels mounted on cylinder rotators.

Illustrated is a Courtburn Model OP 5 Operator's Platform being used to accommodate two men, while welding a 16 ft. diameter circular fabrication standing in the vertical position. The hydraulic pump for raising and lowering the platform can be seen conveniently positioned adjacent to the welder.

The Operator's Platform illustrated right was built for the A.P.V. Co. Ltd., Crawley, for welding their aluminium vessels. A welder can be hydraulically raised up to 15 ft. 7 in. from the floor by operating the hand pump on the platform.



COURTBURN
POSITIONERS LIMITED

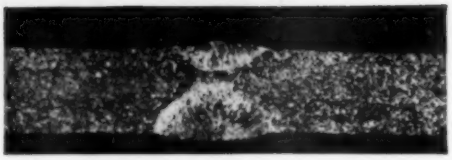
Please write for complete catalogue to:

COURTBURN POSITIONERS LIMITED

KEMPSTON HARDWICK, BEDFORD Telephone Kempston 2341 Telegrams Courtburn Bedford

WELDING OF NON-FERROUS METALS

Metal-arc welding of an 'Everdur' pressure vessel.



This macrograph illustrates the quality of weld easily achieved in 'Everdur' A alloy, using the argon arc process and I.C.I. filler rod.

TECHNICAL NOTES: NO. 4:

Welding 'Everdur'

'Everdur' is the trade name for a range of copper-silicon-manganese alloys made by I.C.I. Metals Division. These alloys are widely used in chemical plant and other applications calling for a material stronger than copper but equally corrosion resistant.

Of all copper alloys, 'Everdur' is the easiest to fusion weld, and autogenous welds of high quality can be made by the gas, carbon arc, tungsten arc and inert-gas metal arc welding processes.

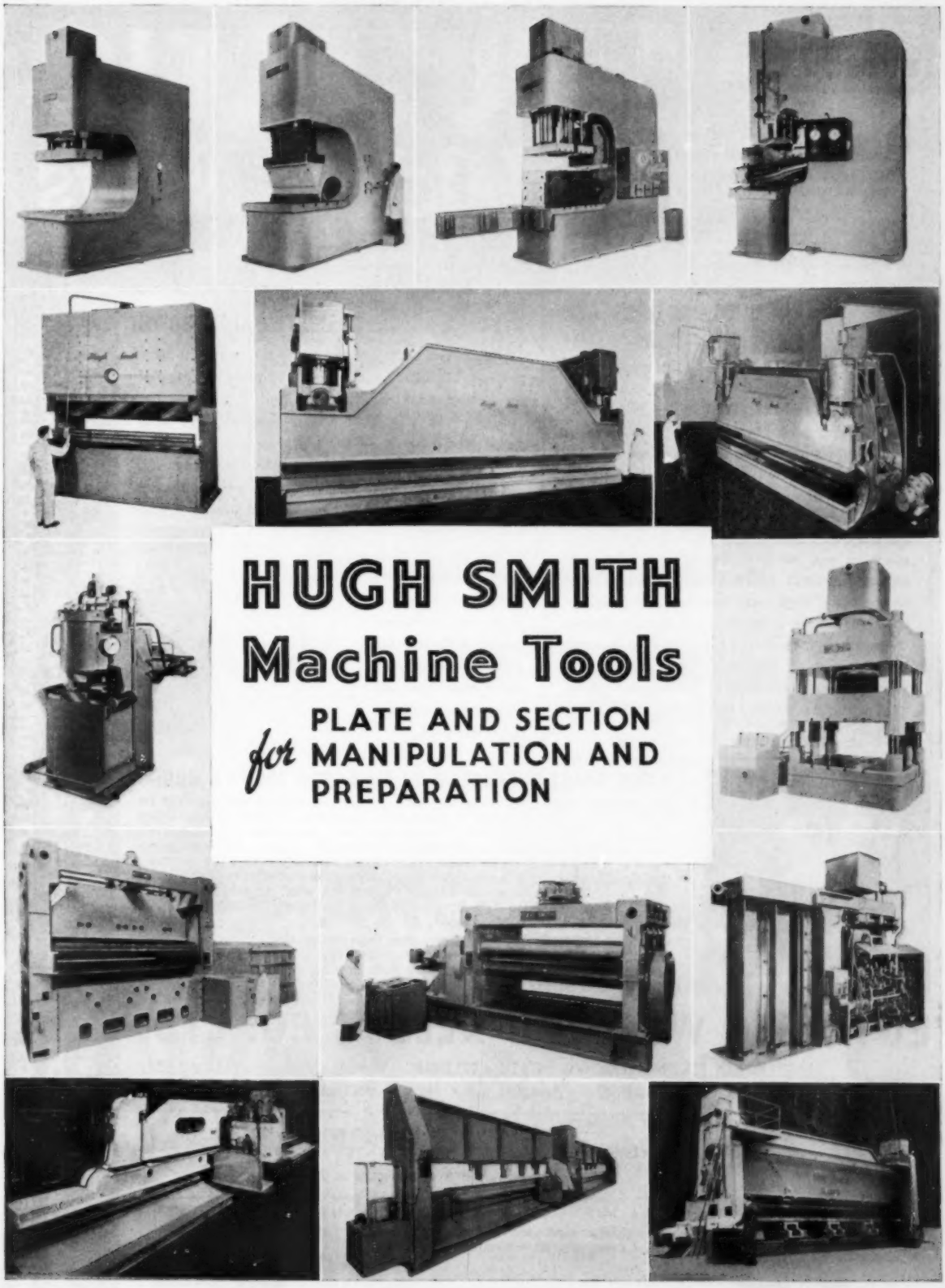
Imperial Chemical Industries Limited, Metals Division, produces large tonnages of non-ferrous metals and alloys for brazed and welded assemblies, and a wide range of rods and wires for brazing and welding.

The Company's Research Department has for many years carried out development work on the joining of metals. The experience gained is freely available to all interested in this subject.

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.I.

ICI METALS DIVISION

M.14



Hugh Smith & Co. (Possil) Ltd., Hamiltonhill Road, Glasgow, N.2.

HISTORY OF "EUTECTIC LOW TEMPERATURE WELDING ALLOYS"

Surface alloying at low heat was first discovered by "Eutectic" in 1904 – used today in over 100,000 plants. "Eutectic" is the originator and sole manufacturer of "Eutectic Low Temperature Welding Alloys" for bonding metals at low heat, minimizing distortion, warping and stress.

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS COMPANY LIMITED, FELTHAM, MDDX.

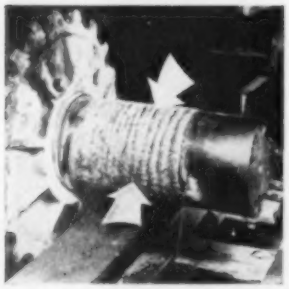
THE HISTORY OF "LOW HEAT INPUT" WELDING

In 1904 the late J. P. H. Wasserman, a pioneer Swiss metallurgist, first observed the phenomenon of surface alloying during brazing operations. His son, Rene D. Wasserman, continued research and perfected the new "surface alloying" metal joining and repair process. Today, advanced Eutectic "Low Temperature Welding Alloys" minimize or eliminate the distortion, warping, embrittlement, cracking and other undesirable metallurgical changes in base metals which can occur with conventional high heat materials. Throughout Great Britain, a large force of factory-trained technical representatives is bringing to industry the benefits of Eutectic's "Low Heat Input" Process. Take advantage of this free service by completing the coupon below and posting it to us today.

XYRON 2-24 SAVES COSTLY SHUT-DOWN

Fractures suddenly developed in the cast iron base of this cable hoist. Faced with a complete stoppage of production and a lengthy repair job, the manufacturer used Eutectic Xyron 2-24. With this high quality, "Low Amp" electrode, the fractures were repaired in position. Dismantling and preheat were not necessary. Xyron 2-24 enables the heaviest and most complicated cast iron jobs to be "cold" welded in all positions. Preheat and after-cooling necessary with conventional material are eliminated. Xyron 2-24 operates at low amperage A.C. or D.C., gives an extremely dense, smooth deposit, with a tensile strength of 13½ tons p.s.i.

EUTECTIC 'LOW TEMPERATURE WELDING ALLOYS' FORMULATED FOR 'LOW HEAT INPUT' BONDING OF ALL METALS INCREASE SAVINGS BY SALVAGE AND REPAIR, SOLVE PRODUCTION PROBLEMS



9 TON SHAFT OVERLAYED BY EUTECROD 185 IN 8 HOURS

The bearing end of this nine-ton, 23 ft. stoker drive shaft was found to be badly worn, after 21 years of continuous operation. A large public utility company thought repair would be lengthy and expensive until Eutectic's Technical Representatives suggested EutecRod 185, a patented BronzoChrom overlay with the highest resistance to frictional wear. EutecRod 185 repaired the shaft in only eight hours, with great savings in material and labour. The overlays were applied without raising the shaft above dull red in colour, and EutecRod 185 bonded without fusion of the base metal at between 540° and 650° C.

EutecRod 185 whilst harder and tougher than conventional overlays is fully machinable. Characteristics include high ductility, low coefficient of friction and excellent resistance to corrosion with highest resistance to wear and impact.

EUTECTIC WELDING ALLOYS CO. LTD.

NORTH FELTHAM TRADING ESTATE · FELTHAM · MIDDX · *Phone:* FELtham 6571

NEW YORK · LAUSANNE · FRANKFURT (m) · PARIS · MONTREAL · SAO PAULO · MEXICO

EUTECTIC WELDING ALLOYS CO. LTD.,
NORTH FELTHAM TRADING ESTATE · FELTHAM · MIDDX.

I would like further free information on the following:

☐ *EutecRod 185 FC* ☐ *XYRON 2/24* ☐ *Free 180 page pocket Welding Data Book*

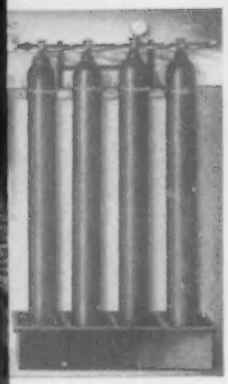
☐ *Please send your Technical Representative for free consultation/demonstration.*

NAME .....

ADDRESS .....

B.W.J. 4

Photograph illustrating the FUSARC/CO_2 process by courtesy of Quasi-Arc Limited



The use of low pressure CO_2 gas as an inert shield in the welding of steels is increasing. CO_2 is not only cheap — it enables high quality welds to be made in the shortest time.

Where automatic welding machines have been specially modified to use this technique, the simplicity, ease of slag removal and high speed of welding have been found most impressive. On one differential housing, for example, welding time has been reduced from 105 to 23 seconds.

CO_2 ARC WELDING

DCL

The Carbon Dioxide Department of the D.C.L., with 30 years' experience of supplying CO_2 to industry, installs and maintains all necessary storage and gas supply equipment for CO_2 arc welding.

Single 28 lb. cylinders are supplied for experimental purposes. For continuous operation multi-cylinder racks are available discharging into a manifold. A typical transportable rack gives a continuous supply of gas at each of 4 points with individually controlled flows up to 6 lbs/hr. CO_2 is also available in solid form for use with 'Cardice' Converters.

Bulk liquid can be pumped direct from the Company's road tankers into customers' static tanks (of capacity $1\frac{1}{2}$ or 6 tons) without interrupting the flow of CO_2 to the operators.

All enquiries for further information should be addressed to:

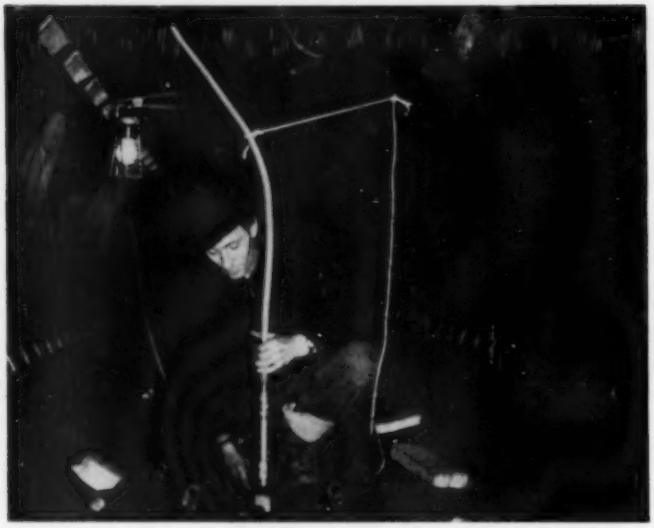
THE DISTILLERS COMPANY LIMITED

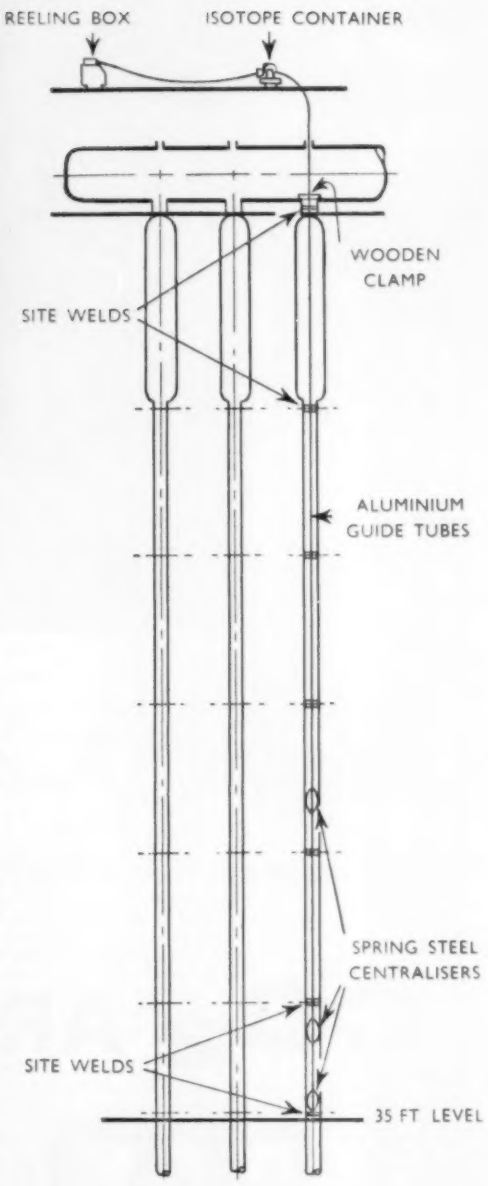
Chemical Division — Carbon Dioxide Department

Devonshire House, Piccadilly W.1

Telephone: Mayfair 8867

Depots and Branches throughout the U.K.





Photograph and illustration by courtesy of International Combustion Limited

Projecting a source 92 feet

Four horizontal welds in the high-pressure downcomer pipe-lines at High Marnham had to be examined at distances of 1ft, 21ft, 81ft and 92ft below the boiler drum. The bore of the pipes could be reached only from the boiler drum itself, so the radio-active source would need to be projected downwards over long distances to reach the final welds on each pipe-line.

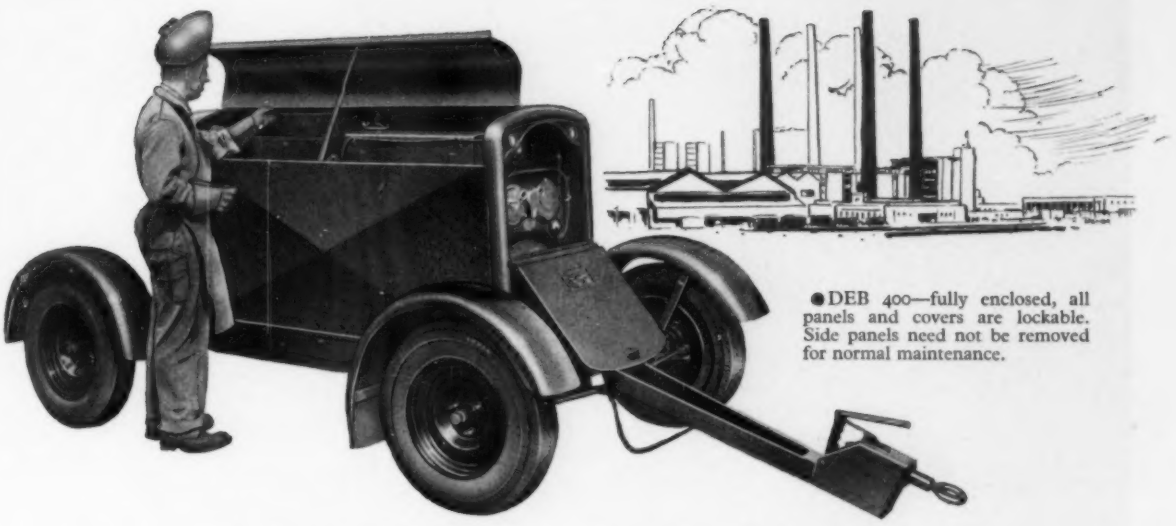
The container weighed 400lb so could not be conveyed over the distance. The problem, therefore, was — how to transport the source? Obviously, the source would have to leave the container and, under safe conditions, make a "tour" of the welds, stopping at each weld for the exposure and moving on to the next.

The engineers of International Combustion Limited solved the problem by designing a reeling box to contain 125ft of cable. They positioned the container on staging over the drum, and fed the cable, with source attached, into a flexible guide tube which was passed through the superheater inlet nozzle on top of the drum and down rigid aluminium tubes to the bottom of the downcomer main. Spring steel strips were fixed at intervals to hold the tubes centrally in the bore of the pipe, and a 100ft tape measure was fastened to the guide tube to ensure accurate positioning of the source in relation to the X-ray film.

This is one of a series of case histories being published in the technical Press, showing how leading industrial radiologists are finding solutions to their day-to-day problems. There is no problem in choosing the right film for a particular job. Kodak make five kinds of industrial X-ray film, covering every requirement from finest resolution to highest speed. ('Crystallex' film was used in the case quoted here.)

Kodak Industrial X-ray Films

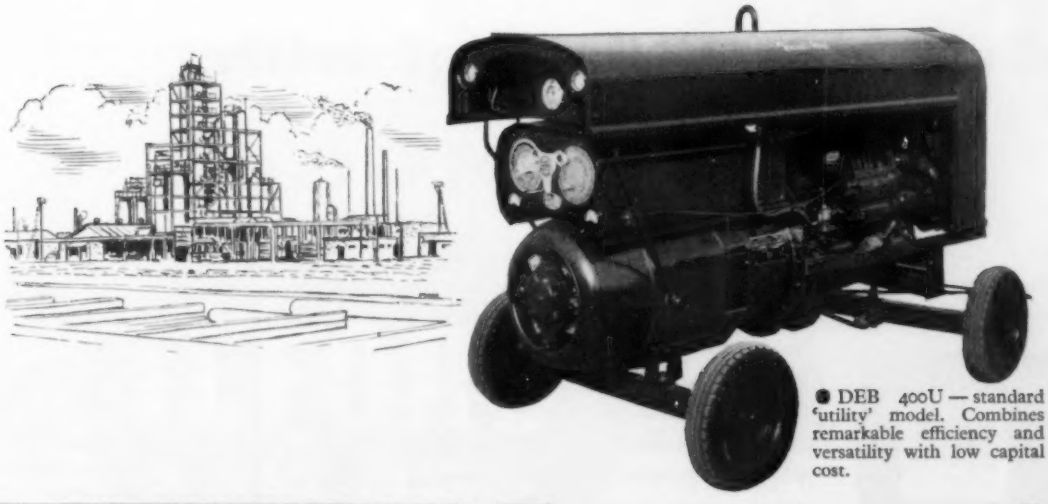
Kodak Limited, Industrial Sales Division,
Kodak House, Kingsway, London, W.C.2.



● DEB 400—fully enclosed, all panels and covers are lockable. Side panels need not be removed for normal maintenance.

All these features in the NEW QUASI-ARC engine-driven welding sets

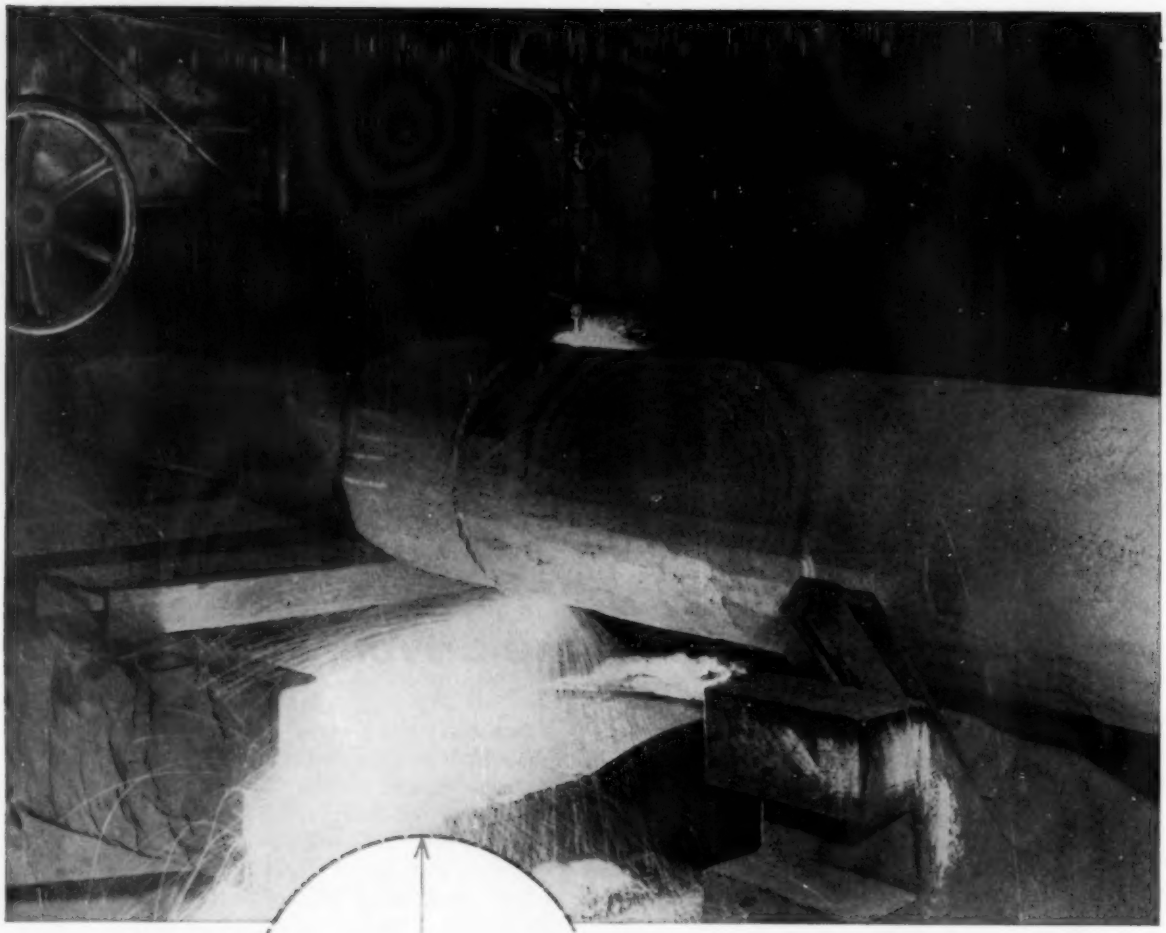
* Sturdy construction for the toughest site work
* Light in weight, handy and compact for easy manoeuvrability
* Complete range of undergear available to give maximum mobility in all conditions
* New Quasi-Arc generator has flexibility which makes equipment suitable for large variety of applications and all types of electrodes
* Powerful Fordson Major 4-cylinder Diesel engine (Alternative engines including Perkins L4 can be fitted)
* Simple, grouped controls
* Fully automatic idling device for economy
* Electric and hand starting on all models
* Current range 40-400 amperes
* For further details and specifications please write for leaflet T.C. 859A.



● DEB 400U — standard 'utility' model. Combines remarkable efficiency and versatility with low capital cost.

QUASI-ARC

QUASI-ARC LIMITED · BILSTON · STAFFORDSHIRE



Cutting 22" steel with PYROGAS

This photograph was taken at the Dennystoun Forge, Dumbarton and shows machine cutting of a 22" diameter steel shaft. The fuel gas—Pyrogas, and the B.G.T. cutting nozzle were both supplied by Saturn Industrial Gases Limited.

Pyrogas—the versatile fuel gas—is unsurpassed for cutting, heating, brazing and metal spraying and has been proved in industry for many years. SUPER-PYROGAS, with its patented chemical additive, has a higher flame intensity than Pyrogas and is used particularly for machine cutting.

We also manufacture Saturn High Purity Argon and a full range of cutting and welding equipment including Saturn-Hivolt Surge Injector Argon Arc Welding Units.

We give daily deliveries of Gases, supply equipment, and provide a prompt repair service from all our branches.

SATURN INDUSTRIAL GASES LTD

Group Head Office: Gordon Road, Southall, Middlesex.

Branches: Birmingham, Glasgow, Lymington, Manchester, Sheffield, Sunderland, Thornaby-on-Tees.

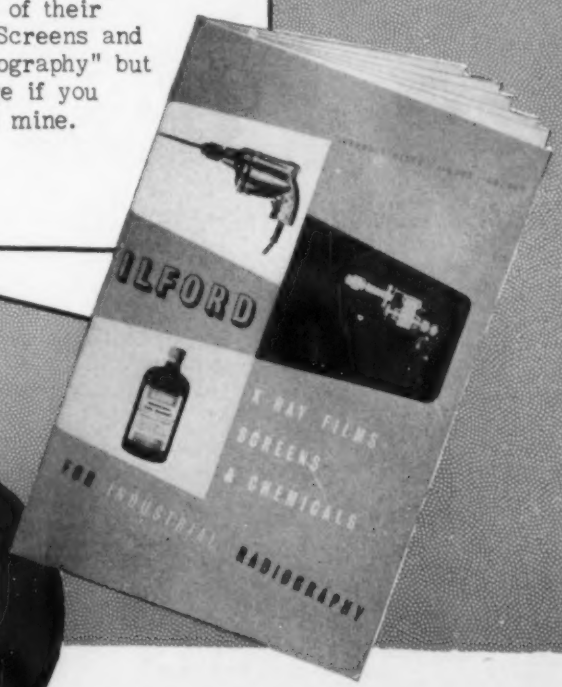
Between experts...

(2)

and if we could land the contract for radiographing these new light-alloy castings, it would be a fine bread-and-butter job for the new X-ray unit.

We must put up a good show, so I suggest you take along some of those Al/Mg undercarriage component rejects which you took on Ilford Industrial X-ray film C. The flaw discrimination is really quite extraordinary.

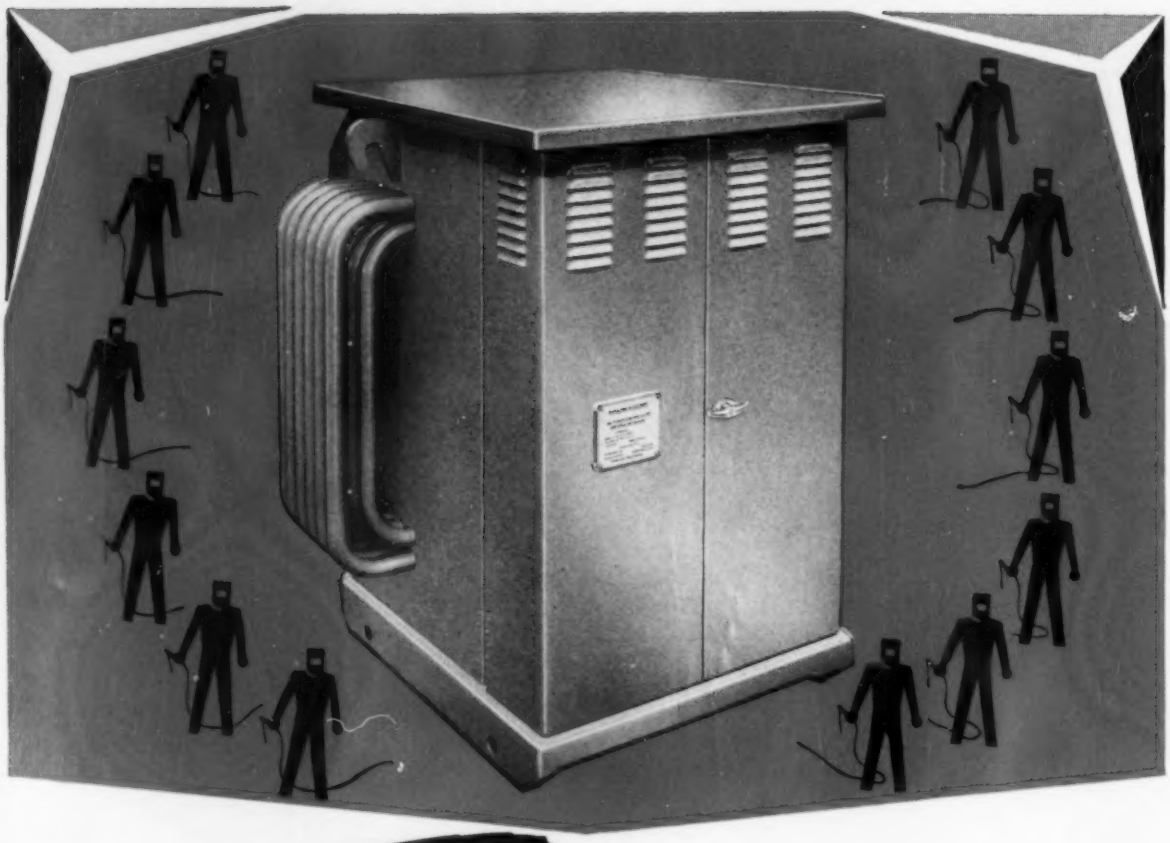
By the way, you should see what the Ilford people have to say about their Industrial X-ray film G for gamma-ray work. I'm attaching my copy of their booklet "Ilford X-ray Films, Screens and Chemicals for Industrial Radiography" but they'll send one free of charge if you write. Don't forget to return mine.



ILFORD
X-RAY FILMS

FOR INDUSTRIAL RADIOGRAPHY

ILFORD LIMITED . ILFORD . ESSEX



The FIRST multi-operator welding transformer with '3 in 1' compactness

A new range of multi-operator welding transformers with inbuilt power factor correction capacitors and fuse-switch units

AVAILABLE FROM STOCK

'ENGLISH ELECTRIC' LWMC multi-operator welding equipments are designed for indoor or outdoor use. Built as a single unit, the transformer is mounted in a special tank with a dry compartment housing the power factor correction capacitor, combination fuse switch, H.V. terminals, thermometer pocket, breather and oil level gauge. This compartment has full length access doors provided with handle and lock. Besides being weather-, vermin-, and tamper-proof, these 'ENGLISH ELECTRIC' combination transformers are transportable and can be easily platform-mounted. They are available for 3, 6, 9 or 12 operators at 350 amps. each in conjunction with standard regulators. *Write for full information.*

'ENGLISH ELECTRIC'

welding equipment and electrodes

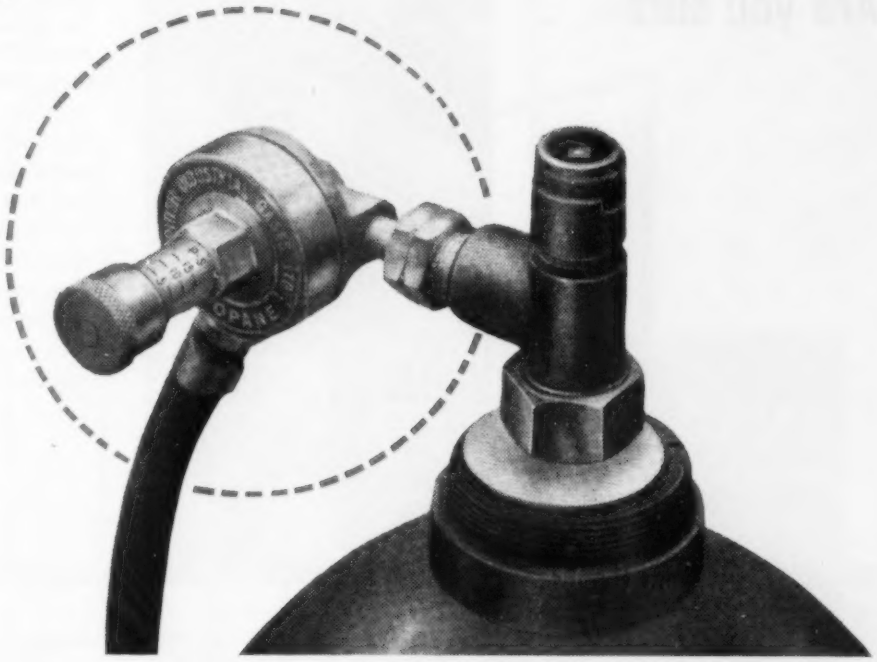
THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2

Welding Equipment Department, East Lancashire Road, Liverpool, 10. Telephone No: Aintree 3641

WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

WA.21K8

maintaining **B.I.G.** *excellence . . .*



the new B.I.G. PROPANE *regulator*

Precision made, this simple to operate Single-Stage Regulator is designed for use with Propane, Pyrogas or similar fuel gas for heating and cutting operations.

It is particularly suitable for use in steel-works, shipbuilding and similar heavy Industries where its robust construction will withstand rough usage and give a long trouble-free service.

Inlet pressure up to 100 lbs. p.s.i.
Outlet „ „ „ 15 „ „
Maximum flow „ „ 500 cu. ft. per hour.
Over-all dimensions 5″×3″×4″. Weight 2 lbs.
Suitable only for Propane, Pyrogas, Bottogas.
A quality product at low cost.

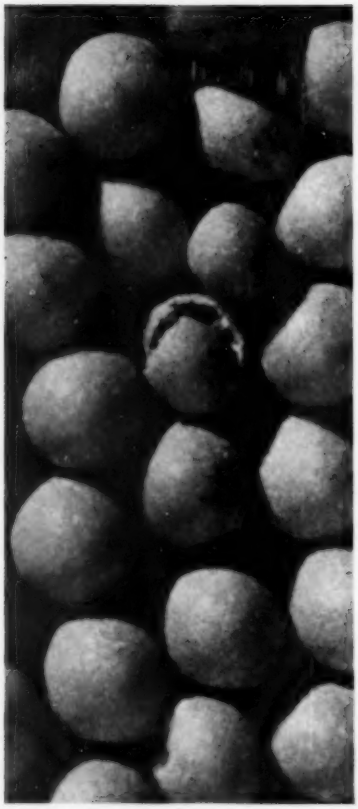
British Industrial Gases Limited

700, GT. CAMBRIDGE RD, ENFIELD, MIDDX. Telephone: **ENField 4022,** Telex: **24128**

Sales and Technical Assistance available in most areas

Rainbow 1533

Are you sure . . .



that this picture shows a clutch of turtles' eggs? Maybe you're not too sure.*
But one thing you can be sure about – the Suffolk Iron Foundry has the answer to any welding problem. Our team of highly-qualified technicians is always available. With their fleet of vans specially equipped with the latest oxy-acetylene apparatus they can solve your problem on the spot. All you have to do is ring Stowmarket 183.
*(*The "eggs" are really the heads of matches*).

SUFFOLK IRON FOUNDRY (1920) LTD **STOWMARKET, SUFFOLK**

ANGLO-SWEDISH

ELECTRIC WELDING CO. LTD

FIRST CLASS WELDING UNDER THE STRICTEST SUPERVISION

We have ample facilities for handling top-grade welding repairs to boilers, castings, machine parts, etc., with expert technicians, for Fabrication work, Structural Steel work, Tank construction and Electric Stud Welding.

ANGLO-SWEDISH ELECTRIC WELDING CO. LTD
Head Office: WOOD WHARF · GREENWICH · LONDON SE10
Telephone: GREenwich 2024-5

Phone, Call or write us NOW for immediate service
LONDON · GLASGOW · LEITH
NEWCASTLE · LIVERPOOL

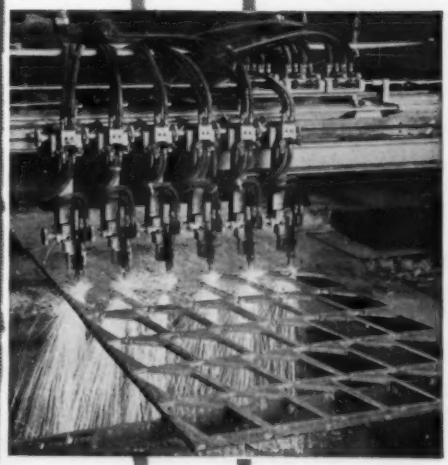
FREE COLOUR BROCHURE

THIS DESCRIPTIVE COLOUR BROCHURE SENT **FREE** ON REQUEST

HANCOCK the first name in oxygen cutting

HANCOCK the first name in oxygen cutting

HANCOCK the first name in oxygen cutting



1st

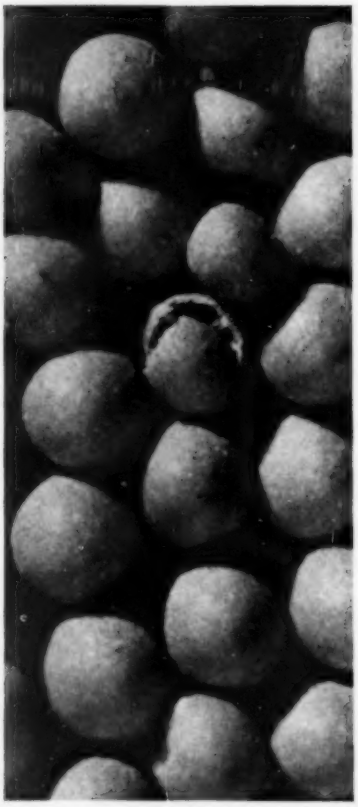
From the very earliest days, Hancock have introduced and pioneered every important development in the design of oxygen cutting machines.
For nearly 40 years they have been the pacemakers —their machines have set the standard in design, construction, performance and long life.
In the future, too, you can be sure that the first name in oxygen cutting will be HANCOCK.

1st The first name in OXYGEN CUTTING HANCOCK HANCOCK CUTTING MACHINES

HANCOCK & CO. (Engineers) LTD. Progress Way, Croydon, Surrey
Telephone: Croydon 1908 (3 lines)

Tib. 135

Are you sure . . .



that this picture shows a clutch of turtles' eggs? Maybe you're not too sure.*
But one thing you can be sure about – the Suffolk Iron Foundry has the answer to any welding problem. Our team of highly-qualified technicians is always available. With their fleet of vans specially equipped with the latest oxy-acetylene apparatus they can solve your problem on the spot. All you have to do is ring Stowmarket 183.
*(*The "eggs" are really the heads of matches*).

SUFFOLK IRON FOUNDRY (1920) LTD **STOWMARKET, SUFFOLK**

ANGLO-SWEDISH

ELECTRIC WELDING CO. LTD

FIRST CLASS WELDING UNDER THE STRICTEST SUPERVISION

We have ample facilities for handling top-grade welding repairs to boilers, castings, machine parts, etc., with expert technicians, for Fabrication work, Structural Steel work, Tank construction and Electric Stud Welding.

ANGLO-SWEDISH ELECTRIC WELDING CO. LTD
Head Office: WOOD WHARF · GREENWICH · LONDON SE10
Telephone: GREenwich 2024-5

Phone, Call or write us NOW for immediate service
LONDON · GLASGOW · LEITH
NEWCASTLE · LIVERPOOL

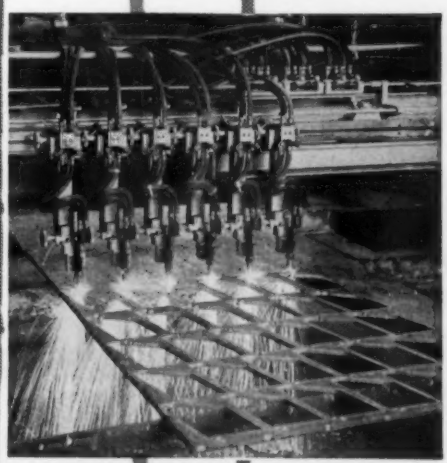
FREE COLOUR BROCHURE

THIS DESCRIPTIVE COLOUR BROCHURE SENT **FREE** ON REQUEST

HANCOCK the first name in oxygen cutting

HANCOCK the first name in oxygen cutting

HANCOCK the first name in oxygen cutting



st

From the very earliest days, Hancock have
introduced and pioneered every
important development in the design
of oxygen cutting machines.
For nearly 40 years they have been the pacemakers
—their machines have set the standard in design,
construction, performance and long life.
In the future, too, you can be sure that
the first name in oxygen cutting will be HANCOCK.

HANCOCK & CO. (Engineers) LTD. Progress Way, Croydon, Surrey
Telephone: Croydon 1908 (3 lines)

1st The first name in OXYGEN CUTTING HANCOCK CUTTING MACHINES

Tib. 135

Lloyds Class 1 Fusion Welding—Robey welding—is exhaustively tested at every stage—in the laboratory, by X-ray, by rigid stage-by-stage inspection, by hydraulic and other methods. The keynote is safety, but this is just one aspect of our welded work. Delivery-on-time is another. Competitive pricing a third. And, not least, **exact** fulfilment of specifications.

Things like this are taken for granted at Robey's—but they make a lot of difference for our many customers.

ROBEY
OF LINCOLN

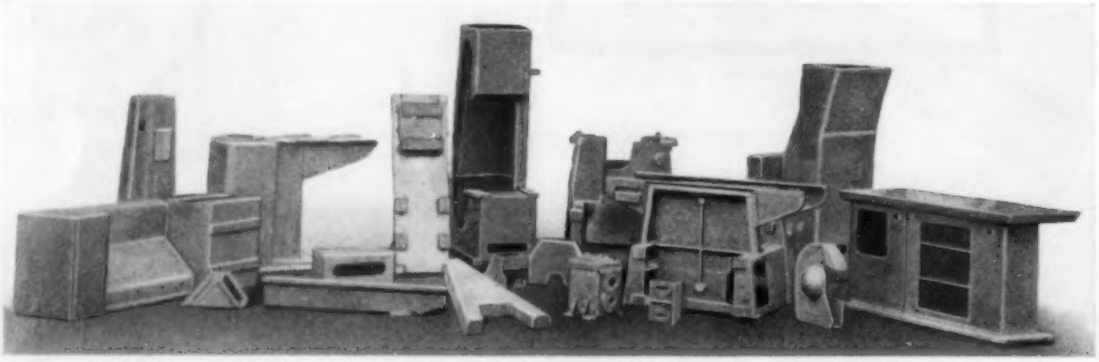
Robey & Co. Ltd. Lincoln

London office: 11 Princes Street, Hanover Sq., London, W.1

STEEL FABRICATIONS

SHEARING - PROFILE CUTTING
SHOT BLASTING & ZINC SPRAYING
can be offered

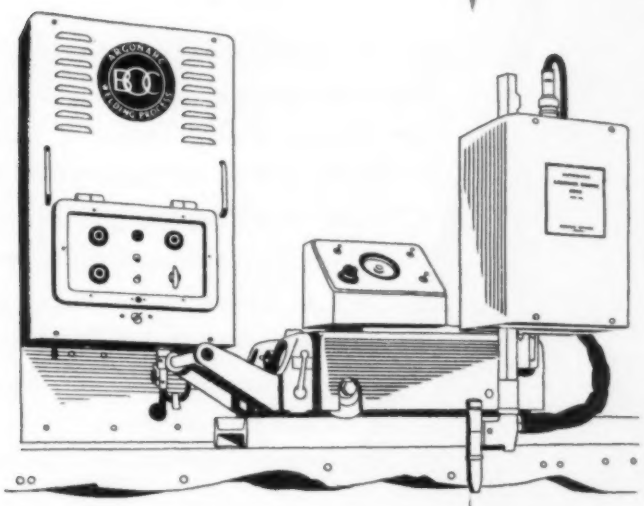
These are a few of the many examples of steel fabrications made by Douglas Barnes for the machine tool and wood-working trade. This also applies to all trades which require steel fabrications



May we have the pleasure of quoting for your fabrications - either prototype or batch quantities?

DOUGLAS BARNES LTD. VICTORIA WORKS - HECKMONDWIKE YORKSHIRE TELEPHONE: 408 & 972

FROM BRITISH OXYGEN — FOR BRITISH INDUSTRY



ARC LENGTH CONTROL

New automatic Argonarc welding head

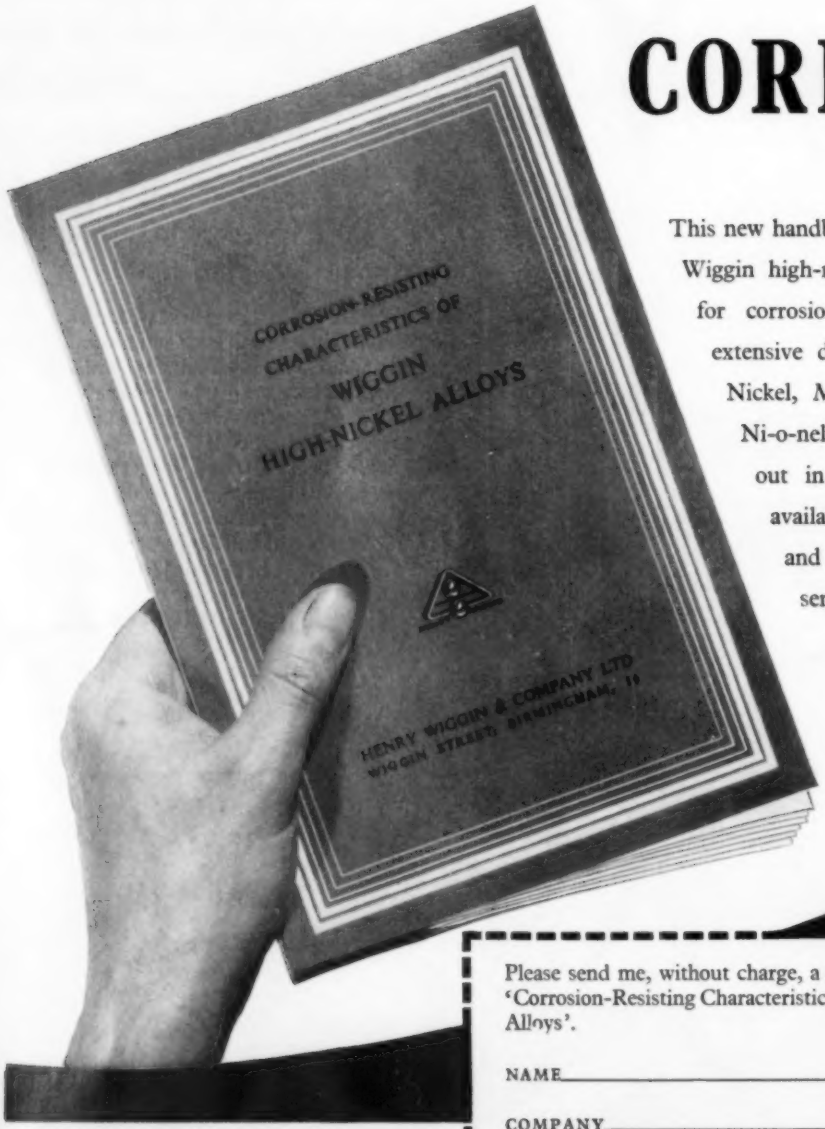
This new Argonarc welding head with arc length control adjusts itself automatically to undulations in the metal surface to maintain a constant arc length at a pre-set voltage . . . provides all-electrical features for complete welding cycle . . . is suitable for use with A.C. or D.C. arcs and is voltage stabilized to the degree of plus or minus 10 volts . . . the control circuit is sensitive to a change in arc voltage of 0.05 volts . . . response time 4 cycles . . . can be mounted for high quality circumferential, longitudinal or contour welding in the full range of metals associated with the Argonarc process.
Write for fully illustrated literature.

BOC BRITISH OXYGEN

British Oxygen Gases Ltd., Industrial Division, Spencer House, 27 St. James's Place, London S.W.1

Knowing where to find the answers on

CORROSION



This new handbook describes in detail the many Wiggin high-nickel alloys specially developed for corrosion-resisting duties. It includes extensive data on the properties of 'AT' Nickel, Monel, Inconel, Corronel B and Ni-o-nel, and gives results of tests carried out in many corrosive media. It is available, without charge, to designers and chemical engineers. May we send you a copy?

Please send me, without charge, a copy of your publication 'Corrosion-Resisting Characteristics of Wiggin High-Nickel Alloys'.

NAME_____

COMPANY_____

_____

Publications will be sent to private address, if preferred.

BW.

WIGGIN

***KNOW* NICKEL ALLOYS**

'MONEL', 'INCONEL', 'CORRONEL' AND 'NI-O-NEL' ARE REGISTERED TRADE MARKS

HENRY WIGGIN AND COMPANY LIMITED, WIGGIN STREET, BIRMINGHAM 16

TGA CF

THE INSTITUTE OF WELDING

54 Princes Gate, London, S.W.7

◆

COUNCIL and OFFICERS

PRESIDENT
J. STRONG

VICE-PRESIDENTS
A. CLIFFORD HARTLEY, C.B.E. G. ROBERTS
E. SEYMOUR-SEMPER

PAST-PRESIDENT
SIR CHARLES LILLICRAP, K.C.B., M.B.E.

HONORARY TREASURER
W. E. HARRISS

Chairman of Executive Committee: R. E. G. WEDDELL

Representatives of Industrial Corporate Members

E. V. BEATSON
E. F. BURFORD
C. HUMPHREY DAVY
J. A. McWILLIAM
E. S. WADDINGTON
DR. R. WECK

Representatives of Fellows, Members, and Associate Members

V. W. CLACK
F. CLARK, M.B.E.
J. A. DORRAT
E. FLINTHAM
E. FUCHS
E. P. S. GARDNER
S. H. GRIFFITHS
DR. N. GROSS
T. McIVER
H. MARTIN
F. A. PARTRIDGE
E. SEYMOUR-SEMPER

Representative of Companions
J. HOOPER

Representative of Associates
J. R. LEWIS

Chairman of B.W.R.A. Council: A. ROBERT JENKINS, J.P.

Chairmen of Standing Committees

Education Committee — DR. E. F. GIBBS
Finance Committee — C. HUMPHREY DAVY
Membership Committee
Programme and Publications Committee — J. F. LANCASTER
Technical Committee — J. A. DORRAT

Representatives of Branches

Birmingham	W. R. HARPER
East Midlands	A. H. SCOTHERN
East of Scotland	J. F. WHEELDON
Eastern Counties	J. EDWARDS
Leeds	R. GARDENER
Liverpool	G. A. O. PRIDGEON
Manchester	J. M. WHITWORTH
North Eastern (Tees-side)	J. W. JACKSON
North Eastern (Tyneside)	W. R. MELLANBY
North London	J. V. THOMAS C. R. THATCHER
Preston	F. PILLING
Sheffield	W. A. JENKINS, J.P.
Southern Counties	J. H. GILLESPIE
South London	Dr. M. C. NICKSON
South Wales	I. B. FORD
South Western	A. J. FRANCIS
West of Scotland	D. M. KERR
Wolverhampton	M. R. LIDDIATT

SECRETARY
G. PARSLOE

BRITISH WELDING RESEARCH ASSOCIATION

29 Park Crescent, London, W.1

◆

COUNCIL and RESEARCH BOARD

PRESIDENT
SIR CHARLES S. LILLICRAP, K.C.B., M.B.E.

PAST-PRESIDENT
SIR WILLIAM J. LARKE, K.B.E.

CHAIRMAN OF COUNCIL
A. ROBERT JENKINS, J.P.

HONORARY TREASURER
W. E. HARRISS

Members of Council

PROF. G. WESLEY AUSTIN, O.B.E.
PROF. J. F. BAKER, O.B.E., F.R.S.
D. J. W. BOAG
J. BROWN
DR. T. W. F. BROWN
H. G. CONWAY
C. HUMPHREY DAVY
E. FORTH
E. J. HILL
F. C. S. L. LEWIN-HARRIS
H. PEARSON LOBNITZ
SIR ANDREW McCANCE, F.R.S.
RICHARD MILES
J. MITCHELL, C.B.E.
PROF. SIR ALFRED PUGSLEY, O.B.E., F.R.S.
R. B. SHEPHEARD, C.B.E.
C. M. SPIELMAN, O.B.E., M.C.
T. STEVENSON
J. STRONG
J. H. N. THOMPSON, M.C.
LT.-COL. J. F. TODHUNTER
W. T. TOWLER, J.P.
DR. M. A. VERNON
DR. E. G. WEST

Research Board

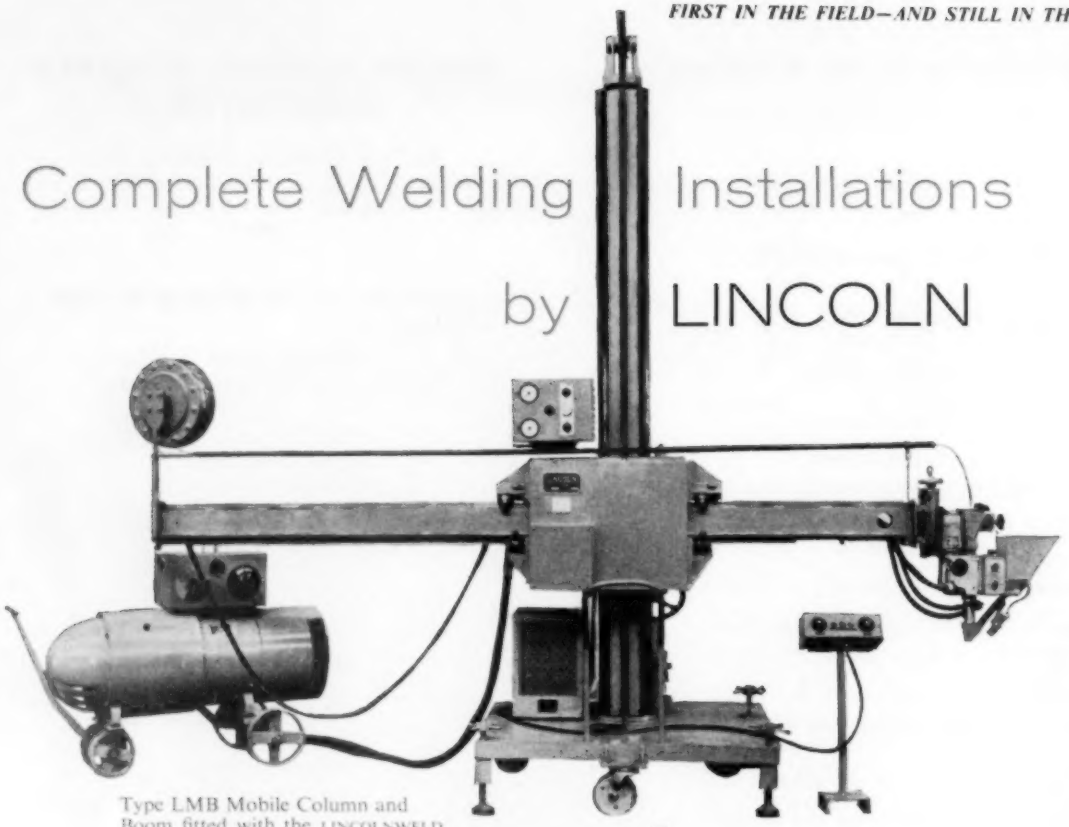
DR. E. G. WEST (*Chairman*)
DR. N. P. ALLEN, F.R.S.
PROF. G. WESLEY AUSTIN, O.B.E.
PROF. J. F. BAKER, O.B.E., F.R.S.
PROF. J. G. BALL
W. BARR, O.B.E.
DR. J. S. BLAIR
DR. N. BOOTH
E. FUCHS
E. P. S. GARDNER
R. M. GOODERHAM
A. H. GOODGER
DR. NICOL GROSS
DR. H. HARRIS
A. ROBERT JENKINS, J.P.
F. KEATING
H. N. PEMBERTON
DR. W. I. PUMPHREY
DR. L. REEVE
G. ROBERTS
PROF. E. C. ROLLASON
DR. H. SUTTON, C.B.E.
N. A. TUCKER
J. TURNBULL
DR. J. H. WEAVING

DIRECTOR OF RESEARCH
DR. RICHARD WECK

SECRETARY
A. O'NEILL

FIRST IN THE FIELD—AND STILL IN THE LEAD

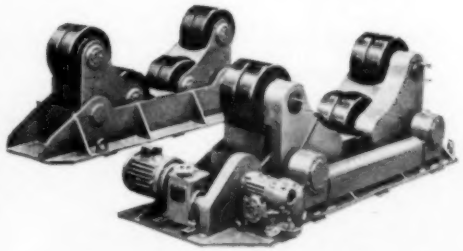
Complete Welding Installations by LINCOLN



Type LMB Mobile Column and Boom fitted with the LINCOLNWELD B.10 Fully Automatic Welding Head.

Whether for hand or automatic welding applications, LINCOLN can offer a complete range of arc welding equipment and work handling fixtures to suit your individual requirements. Typical examples of our latest positioning equipment are shown here, but for full details and specifications of the various types available, please write today to:

Type LSAR 400 Self-Aligning Rotator.



Type LVH Variable Speed Positioner.

LINCOLN ELECTRIC CO LTD

WELWYN GARDEN CITY · HERTFORDSHIRE

WELWYN GARDEN 920 (5 lines) 4581 (5 lines)

Cables & Grams: Shield-Arc, Welwyn Garden City

P.1

BRITISH WELDING JOURNAL

OFFICIAL JOURNAL OF THE INSTITUTE OF WELDING AND THE BRITISH WELDING RESEARCH ASSOCIATION

Incorporating the *TRANSACTIONS* of the Institute and *WELDING RESEARCH*

OCTOBER 1958
Volume 5 Number 10

Subscriptions
Members free:
Extra copies at 7*s.* 6*d.* each
Non-Members:
£5 per annum
Single copies 10*s.* each

Published Monthly

Editor-in-Chief: G. PARSLOE, M.A.
54 Princes Gate, London, S.W.7
(Knightsbridge 8556)

Executive Editor:
C. ROWLAND HARMAN, B.Sc. (Eng.)
Editech
6 Ridge End, Hook Hill Lane
Woking, Surrey
(Woking 2981)

Advertisement Offices:
4 Grosvenor Gardens, London, S.W.1
(Sloane 0063)

Note: Editorial contents copyright. The Institute of Welding and the British Welding Research Association do not hold themselves responsible for statements made or opinions expressed in articles appearing in this Journal.

CONTENTS

INSTITUTE OF WELDING

445 **Metal Arc Welding of Aluminium Bronze Alloys** *By M. K. Williams and W. I. Pumphrey*

449 **Positioners for Automatic Welding of Atomic Reactor Housings** *By W. A. Davis*

454 **New Developments in Arc Welding Processes and Their Applications** *By P. Shaw and D. B. Tait*

465 **Experiments with Self-Guiding Equipment for Aluminium** *By J. E. Tomlinson and R. V. Blewett*

472 **Welding of Some Creep Resisting Steels** *By J. F. Mercer*

475 **Some Guidance on Welding Dissimilar Alloy Steels** *By M. C. T. Bystram*

BRITISH WELDING RESEARCH ASSOCIATION

481 **Weldability of 3½% Ni–Cr–Mo Steel** *By C. L. M. Cottrell and K. Winterton*

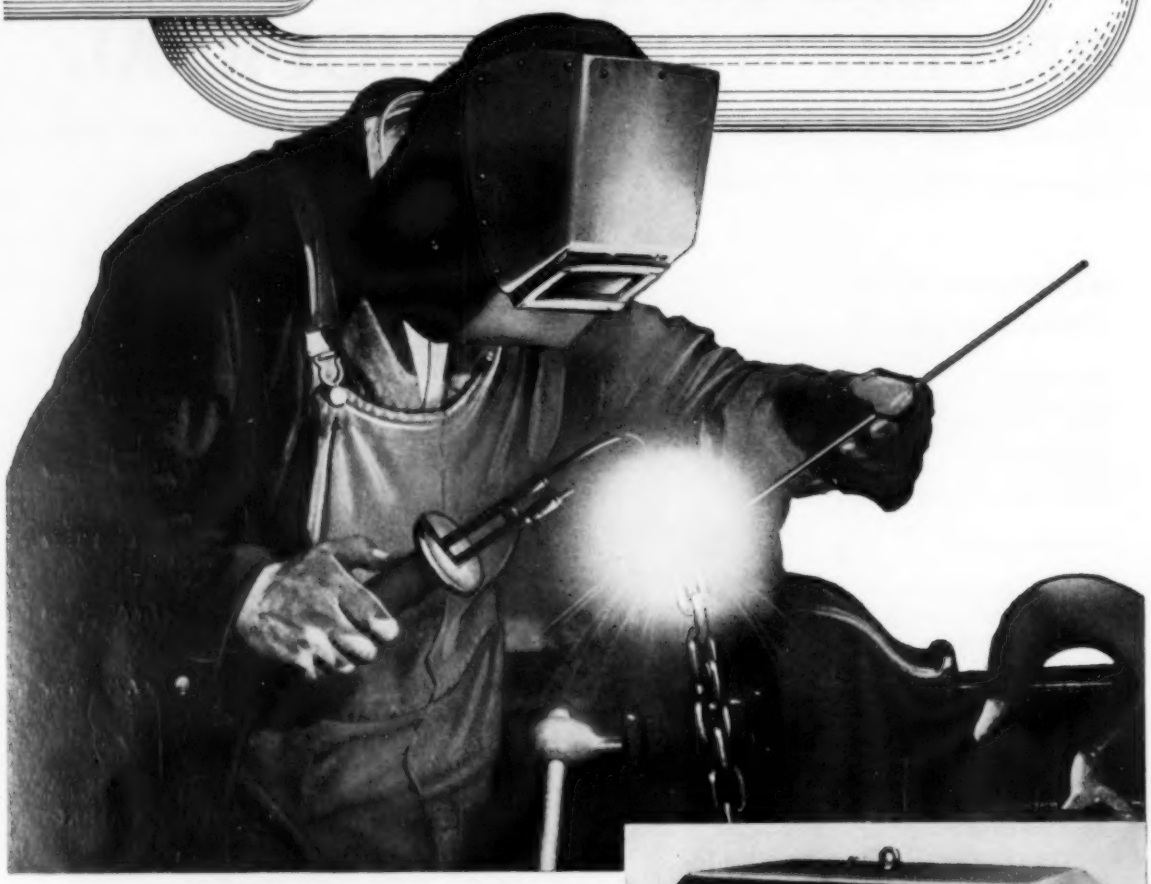
485 NEWS AND ANNOUNCEMENTS

488 CURRENT WELDING LITERATURE

The Institute of Welding 54 Princes Gate, London S.W.7

British Welding Research Association 29 Park Crescent, London W.1

FORGING THE LINK



The Metrovick Atomic Hydrogen method of welding gives complete protection for the weld metal in the fluid state making the process eminently suitable for welding chain where the weld metal must have the same strength and quality as the parent metal.

This desirable feature of Atomic Hydrogen welding, together with the advantage of high welding speed—due to the high arc temperature—can be usefully applied where sound ductile welds are required in mild steel, stainless steel, alloy steel and some non-ferrous metals, e.g. building up surfaces, repairing drills, depositing tool steel cutting edges on mild steel punches and dies, seam welds on fire extinguishers and similar containers liable to rough handling.

Photograph by courtesy of Messrs. Watson & McLean Ltd.

METROPOLITAN-VICKERS
ELECTRICAL CO LTD · TRAFFORD PARK · MANCHESTER, 17

An A.E.I. Company

METROVICK Equipment for More Efficient Welding

L/W 705

Welding
TECHNOLOGY

AUTUMN MEETING, 1958

Metal Arc Welding of Aluminium Bronze Alloys

By M. K. Williams, B.Sc., and W. I. Pumphrey, D.Sc.

SYNOPSIS

THERE is a wide field of application for aluminium bronze metal-arc electrodes, and those depositing a duplex structure produce strong and ductile joints in ferrous and non-ferrous materials.

The paper outlines some of the early difficulties encountered in welding these materials, largely owing to the embrittlement caused by trace impurities. The properties of suitable electrodes and the corresponding welding techniques are described.

Introduction

THE term 'aluminium bronze' covers a range of copper-aluminium alloys which have become recognized in industry for their high strength and excellent resistance to corrosion. Although such alloys have been known for more than a century, little use was made of them before the development of the Durville casting process in 1913 except as a substitute for gold in cheap jewellery.

Production difficulties were associated with the formation of an aluminium oxide film on the surface of the metal during melting and casting. This tough refractory film entered the mould as crumpled folds and was included in the ingot giving rise to porosity and artificial cracks.

New foundry techniques were developed to overcome this problem, and during the Second World War large quantities of castings and forgings in aluminium bronze were used for all manner of fittings for marine and aircraft applications. Since then considerable expansion has taken place in the production of aluminium bronze alloys both as castings and in the form of plate, sheet, and tubes.

The excellent corrosion resistance of these alloys makes them specially suitable for the construction of many types of condensers, heat exchangers, and storage vessels for the chemical and petroleum industries, and has resulted in increasing interest in suitable methods for welding them.

Two distinct types of aluminium bronze are available, one containing less than 8% aluminium and the other containing between 8% and 11% of aluminium, each type being capable of some variation of properties by the addition of other elements such as iron, nickel, or manganese (Table I).

The type I alloys are characterized by a single-phase microstructure and have high cold ductility. They may be fabricated by both hot and cold working and are obtainable in the form of sheet, plate, rod, tube and wire. Heat-treatment consists of a simple anneal to remove the effects of cold work, and no improvement in strength is possible by this means.

The type II alloys have a complex microstructure and are usually hot worked but are capable of a small amount of cold working. The greater proportion of production in these alloys is used as castings or hot forgings. Considerable variations in mechanical properties may be made by a heat-treatment similar to that used for steels.

The thin surface film of aluminium oxide to which these materials owe their high resistance to corrosion was the primary obstacle to early attempts to produce sound welds. The difficulty was overcome by the use

Paper to be presented at the Autumn Meeting in London. Manuscript received 1st July 1958.

Dr. Pumphrey is Research Manager, and Mr. Williams a member of the Research Dept. of Murex Welding Processes Ltd.

Table I

Composition of aluminium–bronze alloys

Type	*Specification*	*Cu, %*	*Al, %*	*Fe, %*	*Ni, %*	*Mn, %*	*Others (max.)*	*U.T.S., tons/sq.in.*	*Elong., %*
I	BS 1867	Rem	6·0– 7·5	Fe + Ni + Mn 1·0–2·5 (opt.)			0·5	25–30	50
	ASTM B 169/52 Alloy D	Rem	6·0– 8·0	1·5–3·5			0·5	31·3–33·5	30–40
II	BS 1400 A.B.1	Rem	8·5–10·5	1·5–3·5	1·0 max.	1·0	0·3 Zn 0·5	32	20
	BS 1400 A.B.2	Rem	8·5–10·5	3·5–5·5	4·5–6·5	1·5	0·3 Zn 0·5	40	12
	ASTM B171/52, Alloy E.	Rem	8·0–11·0	1·5–3·5	4·0–7·0	0·5–2·0	0·5	35·7–40·2	10

of arc welding electrodes with flux coatings designed to ensure adequate removal of the oxide film.

WELDING OF SINGLE PHASE ALLOYS

The ease of cold working and the wide variety of shapes obtainable in the single-phase aluminium bronzes has resulted in these alloys being preferred for the fabrication of corrosion resisting vessels and other structures. So that the corrosion resistance of the material should not be impaired it has been thought desirable to weld with a filler wire giving a deposit matching the plate material. Earlier attempts to weld the 7% Al–bronze alloy with a core wire giving a deposit containing 7% Al gave excellent results provided that the weld was restricted to one or two runs.

If multi-run deposits were made, embrittlement of the weld metal occurred leading to cracks in the joint

Table II[1]

Properties of butt welded joints in 7% aluminium bronze

Plate Thickness, in.	*Electrode gauge*	*Number of runs*	*U.T.S., tons/sq.in.*	*Elong., % On ½ in.*	*On 2 in.*
⅜	8 s.w.g.	1	26·3	64	19
½	8 s.w.g.	4	7·7	16	4
½	¼ in. dia.	3	10·6	34	10
½	8 s.w.g.	4	10·7	22	9
½	8 s.w.g.	4	6·4	18	5

and a consequent deterioration of weld strength and ductility. Typical mechanical test figures[1] are shown in Table II.

A detailed study of cracking in Al–bronze deposits containing 7% Al, made by Rollason and Marsh,[1] indicated that trace impurities in the alloy were the cause of the embrittlement. Grain refinement reduced the tendency to cracking, and multi-run welds using core wires of higher aluminium content to give a duplex type of microstructure were satisfactory.

Further tests by Mantle[2] showed that very small amounts of bismuth or lead in the alloy produced hot-shortness. But welds made with filler wire of controlled purity (less than 0·001% lead and less than 0·0006% bismuth) on both high purity and commercial purity single-phase alloys were satisfactory.

Unpublished work by Biggs and others, carried out in the laboratories of Murex Welding Processes Limited in 1952, suggested that embrittlement was caused by grain boundary films having low strength at high temperature (about 600°C.) but which passed into solution in the grains when the temperature was further increased, thus restoring the ductility of the metal.

The present authors have made a microscopic examination of heat-treated single-phase Al–bronze weld metal and have observed the presence of grain boundary films in a specimen quenched from 600°C., the breaking up and spheroidizing of the films in a specimen quenched after holding for 5 min at 700°C., and the absence of such films in a specimen quenched from 750°C.

An alternative explanation of the cracking was proposed by Shedden and Pumphrey,[3] who suggested that embrittlement may be caused in the single-phase alloys by the formation of a grain boundary film of the brittle gamma 2 phase, this phase being the result of the decomposition of a small amount of the beta phase formed by the segregation of an aluminium rich film around the grains that occurs during the solidification of the alloy.

The embrittling effect of the presence of the gamma 2 phase is demonstrated by the notched bar impact test results obtained by Voce[4] on 'stabilized' duplex aluminium bronzes. The stabilizing treatment consisted of reheating an alloy with an alpha-plus-beta structure to 500°C. for 3 days so as to convert the beta phase into alpha-plus-gamma 2. In these tests it

Table III[4]

Notched-bar impact tests at elevated temperatures

Composition, %	Cu	89·89		87·0
	Al	10·06		10·13
	Fe	0·04		2·80
Temperature, °C.	*Impact value, ft.lb*			
	*Normalized**	*Stabilized†*	*Normalized*	*Stabilized*
Room	60	8	27	6
200	58	10	28	6
250	59	9	34	7
300	80	9	36	8
350	58	9	28	6
400	30	10	15	9
450	15	14	8	9
500	13	16	10	13
550	19	26	21	19
600	78	73	46	46

* 1 hr at 900°C., cooled in air. Structure of matrix: alpha-plus-beta

† Normalized as above, reheated 3 days at 500°C. and cooled during 3 days. Structure of matrix: alpha-plus-(alpha-plus gamma 2)

appears that the impact values increase at about 450°C. and reach a maximum at 600°C., the highest temperature investigated (Table III). The impact values of the stabilized alloys below 450°C. appear to be reasonably constant down to room temperature and are far below those recorded for normalized specimens or those free from gamma 2.

Under welding conditions the rate of cooling of the deposit may conceivably be rapid enough to retain a thin layer of the beta phase at the grain boundaries of a single-phase alloy. This would give a good measure of room temperature ductility but would result in hot shortness, owing to the decomposition of the beta phase into alpha-plus-gamma 2 when the temperature of the solidified metal is raised toward the eutectoid temperature by the heat from superimposed runs.

Microscopic evidence of coring in 7% Al–bronze weld metal indicates that this explanation of the embrittlement of the welds is not wholly unsatisfactory.

On the other hand, bismuth is a recognized cause of embrittlement in copper and some copper alloys. Voce and Hallowes,[5] in an investigation of the embrittlement of deoxidized copper by bismuth, produced relationships between ductility and temperature which closely resemble that published by Rollason and Marsh for aluminium bronze. A minimum ductility was found at about 600°C., but further increase in temperature tended to restore the ductility of the metal. They concluded that at temperatures above 600°C. the decrease in embrittlement is caused by a tendency for a relatively high concentration of bismuth to collect locally at the grain boundaries rather than for a continuous film of bismuth to exist.

The embrittlement of copper by bismuth is apparently similar in nature to the embrittlement of the single-phase aluminium bronzes, which suggests that the cause may be the same with both metals.

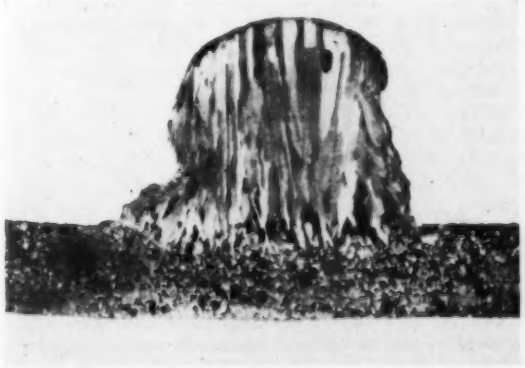
Whichever of the explanations may be correct—either that embrittlement is caused by the presence of grain boundary films of bismuth (or lead), or of the brittle gamma 2 phase—they both share the feature that a refinement of the grain size of the weld metal results in dilution of the embrittling agent. A multi-run weld deposit of a 7% Al–bronze alloy (Fig. 1) consists of a number of large columnar crystals growing continuously through each layer of weld metal, a type of structure which in itself is weak and undesirable. Figure 2 shows a bead of weld metal made up of a number of runs of a metal-arc electrode which produces a deposit containing about 10% Al, 3·5% Fe, remainder Cu. This gives an inherently fine-grained deposit and has been found to resist hot cracking. Satisfactory multi-run welds on the single-phase alloys may be made that are stronger than the parent plate and have sufficient ductility to allow of a 180° bend over a 4*t* former.

COMPLEX ALUMINIUM BRONZES

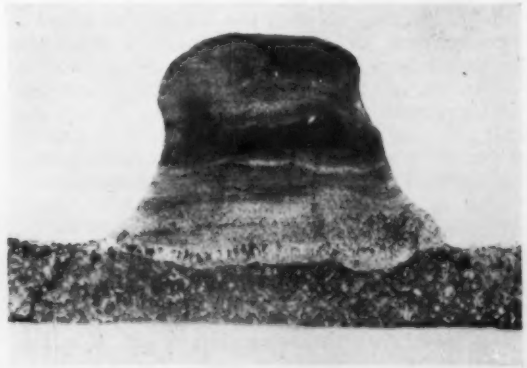
The equilibrium diagram for copper and aluminium shows that the single-phase range extends up to 9·4% Al, but in practice alloys containing more than 8·5% show a duplex structure unless annealed at temperatures below 700°C. Above 9·4% Al the structure remains duplex under all conditions of heat treatment. Whilst the pure alpha alloys are characterized by good cold ductility, alloys with higher aluminium contents, in which a second phase is present, show a decrease in cold ductility with increasing aluminium content. The second phase (beta phase) which is present at high temperatures, however, is relatively soft and ductile when hot, and the alloys are readily forged and hot worked.

At a temperature of 565°C. a change takes place in the constitution of the duplex alloys, and the second (beta) phase decomposes into the alpha and gamma 2 phases; the gamma 2 phase being considerably less ductile than either the alpha or beta phases. In practice, it is desirable to prevent the formation of the gamma 2 phase by quenching the alloys from a temperature higher than 565°C., thus retaining the alpha-plus-beta type of structure.

The properties of these alloys may be modified by the addition of small percentages of iron, nickel, or manganese. Iron is frequently added because of its beneficial effect in stabilizing and grain refining the beta phase, and has the additional effect of increasing the tensile strength of the material by about 2–2½ tons/sq.in. for each 1% of iron present up to about 4% total. It has no deleterious effect in complex aluminium bronze weld metal and is a valuable addition, in that up to about 3½% it helps to restrain the undesirable decomposition of the beta phase into the



1—Multi-run bead in 7% Al-bronze, showing coarse columnar grain structure ×2



2—Multi-run bead in 10%Al-3½%Fe bronze, showing fine grain structure ×2

brittle gamma 2 phase, a process described as self-annealing.[6]

Nickel is also beneficial in increasing the strength of the complex bronzes and helps to maintain the room-temperature ductility in quenched and heat-treated alloys. Its effect is attributed to the formation of a Ni–Al compound in the alloy, taking up aluminium and thus reducing the proportion of the Al-rich beta phase and thereby increasing the quantity of the ductile alpha phase.

Weld metal containing nickel is, however, more susceptible to hot cracking. It has been suggested by Garriott[7] that this is because the Ni–Al compound

Table IV[8]

Hot cracking tests on complex aluminium bronze alloys

(Murex Hot Cracking Machine – Speed 2)

Alloy	*Al, %*	*Ni, %*	*Mn, %*	*Fe, %*	*Cu, %*	*Length of Cracking, in.*
1	8·70	5·30	0·45	5·00	Rem	2·3 1·7
2	8·96	2·30	0·12	1·96	Rem	1·2 1·4
3	8·18	0·20	5·09	4·92	Rem	0·5 0·5

increases the proportion of hot-short alpha phase. The results of some hot cracking tests made by Marsh[8] on weld metal deposited with various complex Al–bronze metal-arc electrodes, given in Table IV, show that the replacement of nickel by manganese has considerably improved the resistance of the alloy to hot cracking. Satisfactory welding of nickel-bearing Al–bronzes with similar weld metal may be accomplished if steps are taken to minimize restraint on the weld. Where restraint is unavoidable, nickel-free complex weld metal should be used.

Manganese has little effect on the structure of the complex bronzes but gives some increase in strength. The presence of manganese in the weld metal, with or without additions of silicon, is claimed to increase the resistance of welds to hot cracking;[9] this is justified to some extent by the test results shown in Table IV.

WELDING TECHNIQUES

Certain features are desirable in a practical aluminium bronze metal-arc electrode. To ensure freedom from hot cracking, an alloy with a duplex structure is to be preferred. Nickel should be absent or, if present, should not exceed 0·5%. For added strength and to stabilize the beta phase, iron is a desirable constituent.

An electrode giving a deposit analysis of 10% Al, 3·5% Fe, 0·5% Ni, and the remainder copper, satisfies these requirements. Such an electrode gives a weld metal of the following mechanical properties:

0·5% Proof stress	21 tons/sq.in.
U.T.S.	38–40 tons/sq.in.
Elong. on 2 in.	18–20%
Red. in area	18%

Satisfactory welds may be obtained provided that certain elementary precautions are taken. It is important that all surfaces to be welded should be clean, dry, and free from grease. The thin surface film of aluminium oxide on the material has a high affinity for moisture, and if this film is not removed porosity in the weld metal may result. Preheating of the parent plate helps to ensure that moisture is absent and also facilitates fusion of the weld metal with the parent plate. It is also good practice to dry the electrodes immediately before use. These precautions help to ensure a good radiographic standard for the welds. Complete removal of slag between runs is necessary, together with a certain amount of dressing of the weld starts to remove protuberances, which may act as slag traps and prevent adequate penetration of superimposed runs.

Copper alloys should be preheated in the range 175°–400°C. to assist the flow of weld metal, which is inclined to be somewhat sluggish. Adequate preheat is indicated by good fusion of the weld metal with the parent plate, good bead shape, and a minimum of spatter. The lower end of the temperature range is usually satisfactory for Al–bronze plate material, whereas the higher end is more suitable if high-tensile brass is being welded. Preheat temperatures up to 600°C. are desirable on heavy-gauge copper.

For use in welding steel a maximum preheating temperature of 175°C. is suitable. This will permit a reduction in welding current to decrease penetration and so prevent the contamination of the weld metal with small globules of undissolved steel, a condition which tends to lower the strength of the joint. If the steel is in a heavily stressed condition, such as may occur with cold forgings or cold rolled plate, a peculiar fault may arise from the generation of cracks in the surface being welded. Alloying of the steel with the aluminium bronze will produce a condition where such cracks are penetrated by the bronze so that they are enlarged and possibly extended into the bronze overlay. This may be prevented by annealing or stress-relieving the steel before welding, or by first covering the surface to be welded with a layer of good quality mild steel weld metal.

OTHER USES FOR ALUMINIUM BRONZE ELECTRODES

The high strength, corrosion resistance, and excellent wear resistant and bearing properties of the complex aluminium bronzes make them ideal alloys for facing steels wherever one or more of these properties is desirable. A typical example has been described by Houston[10] where the slideways of a large drop hammer were overlaid with a complex Al–bronze weld metal. This provided a considerable improvement in the wear resistance of the slides and corresponding economies in maintenance time.

Where a colour match is not essential the high strength of Al–bronze makes it suitable for the repair welding of cast iron, with the added advantages that the weld metal is reasonably ductile and does not dissolve carbon from the cast iron to form hard unmachinable deposits. Low current values should be used in this application to give minimum penetration and so prevent the weld metal from taking up discrete particles of cast iron.

Aluminium bronze electrodes have also been used for welding and repairing high-tensile brasses, copper, and Everdur and may be used on cupro-nickel. They are not suitable, however, for welding the tin bronzes.

CONCLUSIONS

Aluminium bronze metal-arc electrodes have a wide field of application and are capable of giving strong, ductile joints in non-ferrous and ferrous materials. An adequate understanding of the metallurgical principles involved, coupled with a sound technique, will give high quality welds in both similar and dissimilar metals.

Satisfactory multi-run welds on single-phase parent material may be made, using an electrode which deposits weld metal having a duplex structure.

Complex aluminium bronzes containing nickel are best welded with a complex nickel-free Al-bronze electrode.

Ferrous materials may be welded provided that care is taken to prevent too great a dilution of the weld metal with iron from the parent plate.

ACKNOWLEDGMENTS

The authors wish to record their indebtedness to the Directors of Murex Welding Processes Limited for permission to publish this paper.

REFERENCES

1. E. C. ROLLASON and W. D. MARSH: *Welding*, 1947, vol. 15, p. 252.
2. E. C. MANTLE: B.N.F.R.A. Development Report No. 54, February, 1951.
3. J. W. SHEDDEN and W. I. PUMPHREY: *J. Inst. Metals*, 1955, vol. 83, p. 562.
4. E. VOCE: "Aluminium Bronze". Copper Development Association, 1957, p. 139.
5. E. VOCE and A. P. C. HALLOWES: *J. Inst. Metals*, 1947, vol. 73, p. 323.
6. "Aluminium Bronze". Copper Development Association, 1957, p. 59.
7. F. E. GARRIOTT: *Welding J.*, 1952, vol. 31, p. 18.
8. W. D. MARSH: Unpublished results.
9. E. C. ROLLASON: British Patent Specification No. 613,737, June 1946.
10. A. V. HOUSTON: *The Welder*, 1956, vol. 25, No. 128, p. 86.

AUTUMN MEETING, 1958

Positioners for Automatic Welding of Atomic Reactor Housings

By W. A. Davis

SYNOPSIS

THE great lengths of welding and the thickness of plate needed for the fabrication of vessels for nuclear power plant provide suitable conditions for the use of automatic welding equipment.

The paper describes briefly a few of the special positioners used for the automatic welding of vessels for nuclear power plants in the U.S.A.

THE desirability of using automatic welding on field-erected pressure vessels increases with the length of weld and the thickness of plate. Most atomic power reactor housings are quite large and plate thicknesses vary from $\frac{3}{4}$ in. to several inches. It is therefore quite desirable to use automatic welding on such vessels.

In this brief paper a few details are given of positioners that have been devised for the special requirements of handling large curvilinear plates.

KNOLLS ATOMIC POWER LABORATORY

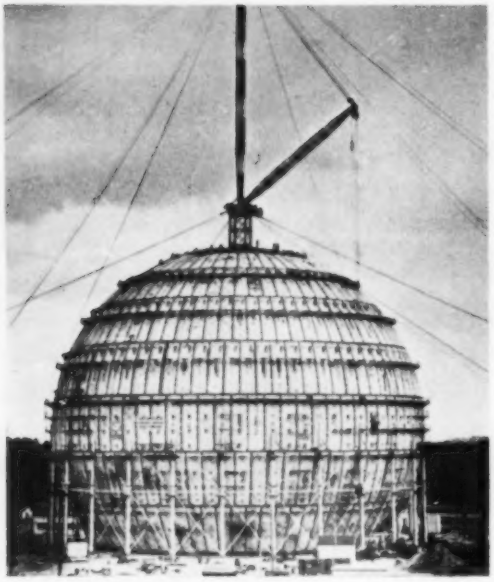
The first large reactor housing erected by the Chicago Bridge & Iron Company was a Hortonsphere for the Knolls Atomic Power Laboratory at West Milton, New York (Fig. 1). This is operated for the U.S. Atomic Energy Commission by the General Electric Company, and one of its first major projects was development work on an atomic power plant for submarine propulsion. The reactor housing was erected during the latter part of 1952 and the first half of 1953.

Paper to be presented at the Autumn Meeting in London. Manuscript received 26th June 1958.
Mr. Davis is on the staff of Chicago Bridge Ltd., London.

Some conception of its size can be gained from the following particulars:

Diameter – 225 ft.
Volume – 6,000,000 cu.ft (26 times more than the next largest sphere at that time)
Thickness – Average 1 in.
Area – Four acres of shell plates
Weld length – Over five miles and every inch radiographed
Weight – 7,000,000 lb of steel
Derrick rigging – Eleven miles of hoist and guy cables

By using welding positioners and assembling four-plate sections on the ground (Fig. 2) over half of the welds were made by automatic machines. This amount was done automatically even though all the circumferential joints were of necessity manually welded in

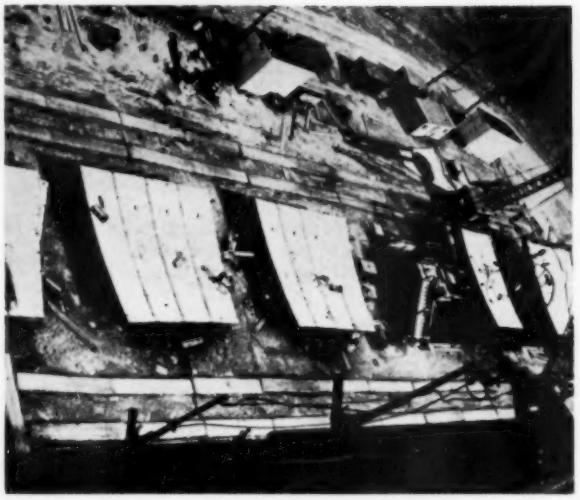


1—Nearly completed 225 ft dia. reactor housing for Knolls Atomic Power Laboratory

position. The decision to use a four-plate assembly was determined more by its size than by its weight.

The first step in the fabrication of the assembly was to automatically weld two single plates together on a tilting frame, which permitted the joint to be kept level at the point of welding. After the two-plate section was welded on one side it was turned over with the help of the crawler crane, and the second side was welded in the same manner.

There were two main welding positioners which combined two 2-plate sections into a four-plate

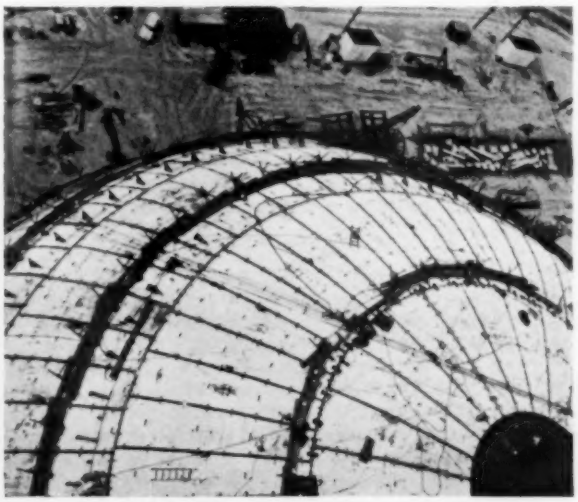


2—Four-plate assemblies on positioners

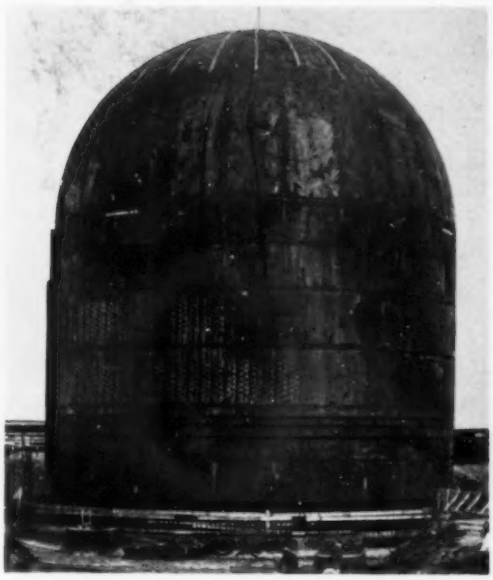
assembly about 32 ft square and weighing about 23 tons. Each positioner consisted of a structural frame having a spherical radius the same as the sphere (Fig. 3). The frame could be rotated 360° about its axis so that joints could be kept level at the point of welding and so that the four-plate sections could be inverted for welding the second side. Four holding down beams clamped the assembly firmly in place for this inversion.

The automatic welding was done using machines developed specifically for this contract. One machine used two welding heads and operated on a 3-phase a.c. supply. One phase was connected to each welding head and the third to the plate itself. Another machine operated on d.c. with straight polarity and used only one welding head.

3—View of two positioners, showing bull wheels used for inverting the tables

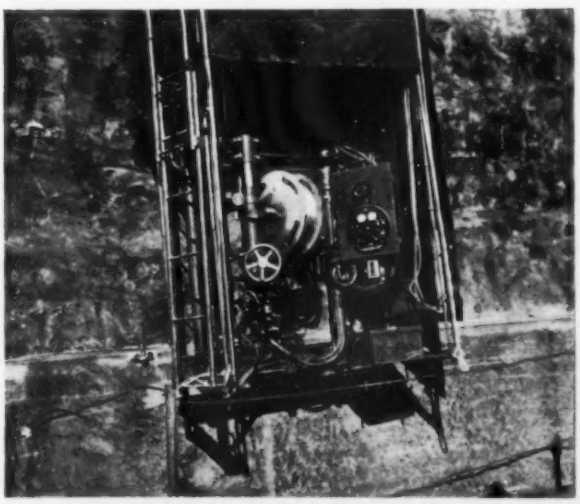


4—View of the Knolls Hortonsphere from the load line of the derrick



5—Completed reactor housing for the Enrico Fermi Atomic Power Plant. The elliptical bottom head is buried in concrete

The handling of the individual plates and two-plate assemblies, and the removal of the four-plate assemblies was done by two crawler cranes. The inverting of each of the main welding positioners was accomplished by running the whip line from one of the cranes to a large wheel, similar to a bull wheel on a derrick, attached to the frame of the positioner. The plate assemblies were erected into the sphere itself with a 100-ton guy derrick located on top of a structural tower. The derrick mast was 170 ft long and its boom 135 ft. On top of its 250-ft tower the derrick mast extended to a height of 420 ft, and dominated the landscape (Fig. 4).



6—Outside part of the automatic girth-seam welder

The erection of this 225 ft sphere took 12 months and the overload pressure test was successfully passed on Labour Day, 1953.

ENRICO FERMI ATOMIC POWER PLANT

At Lagoona Beach, Michigan, south of Detroit, a reactor housing has recently been completed for the Enrico Fermi Atomic Power Plant. This plant is of the fast breeder type and is operated by the Power Reactor Development Company, a non-profit organization having 26 power companies as members. The reactor is for development purposes and is designed to generate 100,000 kW of electric power to be distributed for public use through the facilities of the Detroit Edison Company. The vessel itself is a vertical cylinder 72 ft dia., with an elliptical bottom head and hemispherical top head and having an overall height of 120 ft (Fig. 5). The plate thickness varies from $\frac{3}{8}$ to $1\frac{1}{4}$ in. The total vessel weight is about 720 tons.

Because of the difficulty of making a welding positioner to conform to the varying elliptical, spherical, and cylindrical surfaces it was decided that no pre-assemblies would be made. It was possible, however, to use automatic welding with positioning of a sort to weld the some 2000 ft of circumferential joints in the cylindrical portion of the reactor housing. These horizontal girth joints were welded *in situ* using an automatic girth welder, a submerged-arc welding machine developed and patented by the Chicago Bridge Ltd. (Fig. 6).

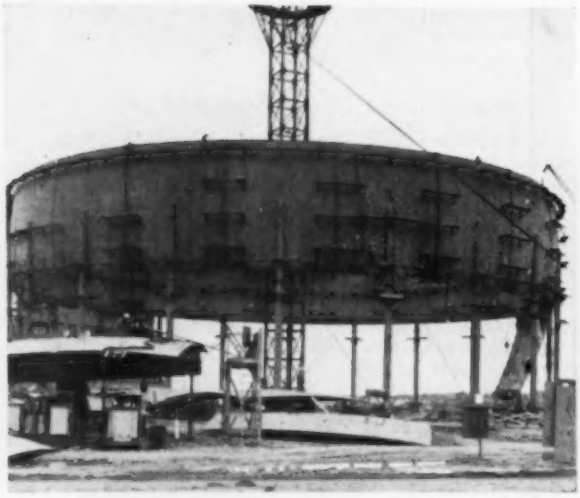
This machine straddles and travels on one horizontal course of plates and welds it to the course below. It carries two automatic welding heads so that both sides of the joint can be welded simultaneously. Endless belts support a substantially stationary bed of flux at the point of welding. As the machine travels additional flux drops onto the belts ahead of the welding nozzles while a vacuum system picks up the unused flux behind the welding head.

By bringing the machine to the work high quality submerged-arc welds can be made without the need for building welding positioners. At the same time the need for higher capacity erection equipment for the heavier preassemblies is avoided. The automatic girth welder is limited to cylindrical shells and as such it is also used extensively throughout the world on storage tanks for petroleum products and for water storage reservoirs.

DRESDEN NUCLEAR POWER STATION

During April 1958 the Chicago Bridge & Iron Company completed a large Hortonsphere designed to serve as a reactor housing for the Dresden Nuclear Power Station. This power plant is financed completely by private funds. The electrical capacity of 180,000 kW is to be the largest in the United States for an atomic reactor. Commonwealth Edison of Chicago, Illinois, will own and operate the plant, which is located about 50 miles south-west of Chicago.

The containment vessel is a 190-ft dia. Hortonsphere with shell plates 1·25–1·40 in. thick. (Figs. 7 and 8). The total weight of the sphere is approximately 7,000,000 lb. There are 492 individual shell plates and about $3\frac{1}{4}$ miles of welded joints, all of them being fully radiographed.



7—Completed equator course of the Dresden reactor Hortonsphere. A four-plate assembly is being welded on the positioner in the foreground

9—An equator course assembly of three plates on the positioner. There is one supporting column for each set of three plates

8—Lower half of Dresden sphere after erection

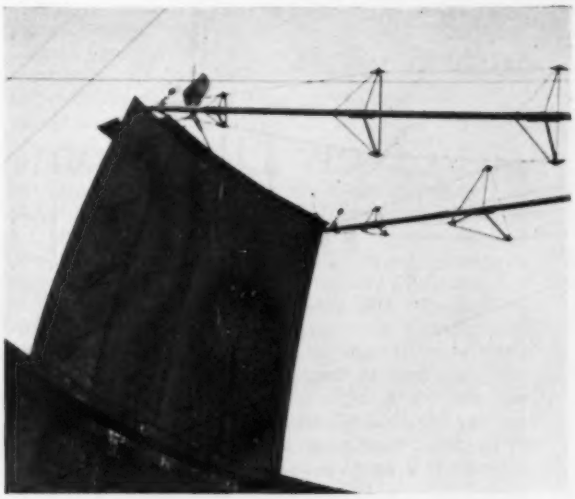
10—Telescopic hydraulic arrester at the end of a positioner

Four-plate sections approximately 35 ft by 36 ft, and weighing as much as 32 tons were pre-assembled on welding positioners. Two welding positioners (or tilt tables as they are commonly named) were used, one for the four-plate assembly concave side up and the other for the same assembly convex side up (Figs. 9 and 10). A 50-ton assembly yard derrick was used to handle the plates on and off the tilt tables as well as to turn the sections over.

The construction of the two positioners was identical except for the contour plates, which differed because the plate assembly was turned over in moving from one table to the next. Each tilt table consisted of a structural frame connected to a centre pylon through a trunnion or universal joint, which allowed angular tilt in any direction. Two identical tilting mechanisms consisting of a motorized winch and cables were located at 90° to each other.

Four individual plates were placed on the first positioner concave side up so that their joints were in line with one of the tilting motions. After fitting the joints for welding the tilting mechanism transverse to the joints was actuated until one of the joints formed part of a great circle whose plane was truly vertical; the joint was then welded by actuating the longitudinal tilting mechanism, so that the point of welding was kept quite level. This operation was repeated on each of the other positions until all of the joints on a four-plate section were welded from the concave side. The assembly was then removed, turned over, placed

11—Four-plate assembly for upper portion of sphere being lifted at the correct angle for positioning during erection



12—First assembly in a course in position and being held by hogged booms

on the second table convex side up and the entire operation repeated.

Some concern was expressed about the use of a cable mechanism to drive the tables, as there is always a possiblity of cable damage and failure. To protect against such a possibility four hydraulic arresters were spaced equally around the positioners between the structural frame and the foundation. An arrester consisted of a tubular cylinder with a piston containing a restricting orifice. The orifice was sized such that the force required to pass the hydraulic fluid through at normal operating speeds was insignificant yet under cable failure the resulting speed of descent was safe.

The use of positioning tables with tilting mechanisms in two directions was an improvement over the inverting table used on the first containment sphere at West Milton, New York. Their greatest advantage is the reduction of plate handling and the ability to weld three joints uninterrupted once the four-plate section is on the table. Another advantage is the elimination of the excavation required under the inverting table. The structural frame also proved to be lighter and smaller in size, lending itself to shipment between contracts.

During erection the completed assemblies were suspended in the correct attitude before they were lifted into position, so as to facilitate landing, particularly in the upper portions of the sphere (Fig. 11). Hogged booms held each assembly in position (Fig. 12) until the whole of one course had been welded and was self-supporting.

FUTURE PLANTS

During the summer and fall of 1958 two additional reactor housings for atomic power plants are to be started. A 160-ft dia. Hortonsphere is being erected for the Consolidated Edison Power Company at Indian Point, New York, north of New York City. Another 125-ft dia. Hortonsphere will be erected for the Yankee Atomic Electric Company at Rowe, Massachusetts. For the erection of both these vessels welding positioners that have tilting mechanisms in two directions, the same as used on the Dresden reactor housings, will be used.

AUTUMN MEETING 1958

New Developments in Arc Welding Processes and Their Application

By P. Shaw, M.A., and D. B. Tait, B.Sc. (Eng.)

SYNOPSIS

The use of iron powder in electrode fluxes has made possible a substantial increase in the deposition rates given by manual electrodes and the particular combination of iron powder with a rutile type low hydrogen electrode has resulted not only in high deposition rates but also in better quality weld metal and lower finishing costs.

The progress of semi-automatic welding, except for the welding of aluminium and other non-ferrous alloys, has been less spectacular, but very great advances have been made in the development of fully automatic processes.

The deposition rates available with fully automatic processes are now so high that the greatest potential increases in output derive from a reduction in setting-up and finishing times or, in other words, from an increase in arc utilization by the provision of better manipulation facilities for both the welding head and the work.

PART I—DEVELOPMENTS IN THE PROCESSES

The essence of all development in arc welding, particularly when related to the welding of steel, is to achieve an increase in productivity. This can be done in two ways; firstly, by developing processes with an inherently high rate of weld metal deposition, and secondly, by using these processes in such a way that the arc utilization is high, so that the time gained by high deposition rates is not lost in ancillary operations. A further feature which must govern all such development is the demand for high metallurgical quality of the deposit, this being particularly relevant to the atomic energy field, where very heavy material is being welded to very high standards of inspection.

Developments in manual electrode welding and in semi-automatic processes are aimed principally at combining a high deposition rate with a high metallurgical quality. With the fully automatic processes, deposition rates are already very high, and developments in this field are principally towards the application of the processes to give high utilisation and a reduction in the time lost in handling and preparing the work.

MANUAL ELECTRODE WELDING

In manual welding, increased deposition speeds are being obtained by the use of iron-powder electrodes. However, the increase achieved by conventional iron-powder electrodes is limited by the fact that, if very high currents are used, the mechanical properties of the weld, particularly elongation, fall off to an unacceptable level. This difficulty has recently been overcome by the introduction of iron-powder electrodes with an essentially rutile coating which deposit low-hydrogen weld metal. With such electrodes, very high currents can be used (*e.g.*, 600 amp with 4 s.w.g. electrodes) to give deposition rates up to 18 lb/hr, with

Table I

Properties of iron-powder electrodes

Tests to the requirements of BS 639; minimum requirement for elongation, 26%

Electrode Type	*Current, Amp*	*Elongation, %*
Conventional iron-powder electrode, 6 s.w.g.	235	27
	300	23
Low-hydrogen rutile iron-powder electrode, 6 s.w.g.	300	31·4[A]
		32·7[B]
	350	27·4[A]
		29·3[B]
	375	32·0[A]
		31·3[B]
	400	31·3[A]
		32·7[B]

A—Test piece machined from weld metal deposited from first half of each electrode.

B—Test piece machined from weld metal deposited from second half of each electrode.

Paper to be presented at the Autumn Meeting in London. Manuscript received 21st July 1958.

Mr. Shaw is Works Director of the Gateshead Works of Quasi-Arc Limited, and Mr. Tait is Manager of the Welding Applications Dept. at the Bilston Works of the Company.

no loss in weld metal ductility. Table I compares the elongation properties of weld metal deposited by conventional and by low-hydrogen rutile iron-powder electrodes; test pieces machined from weld metal from the second half of electrodes used at high currents maintain essentially the same level of ductility.

In many cases, rutile low-hydrogen iron-powder electrodes can be used to replace conventional basic low-hydrogen electrodes; not only is the deposition rate increased by this, but finishing time is reduced, owing to the excellent slag detachability of a rutile slag compared with that of lime fluorspar slags.

Iron-powder additions have also been made to the coatings of electrodes for more specialized applications. These include basic low-hydrogen Class 6- - electrodes, where the iron-powder addition results in a higher metal recovery, and Class 4- - electrodes designed primarily for pressure vessel work. With Class 1 - - cellulose electrodes, the iron powder addition improves the welding properties for vertical downward welding, so that they can be used with either d.c. or a.c. supplies, and again increases metal recovery. Using the vertical downward technique for the welding of pipe butt joints, and vertical seams in such structures as oil storage tanks, considerably increases the overall welding speed, as smaller root gaps can be used without the incidence of piping in the root, back-chipping is not necessary, and inter-pass cleaning and joint reinforcement are reduced. On plates up to $\frac{1}{2}$ in. thick, a considerable increase in welding speeds (up to three times) can be achieved as compared with vertical upward welding. Above this thickness, it is quicker to use a vertical downward technique with iron-powder cellulose electrodes for the root passes, so as to eliminate back-chipping, and then to make the succeeding passes with low-hydrogen rutile iron-powder electrodes using a vertical upwards technique.

SEMI-AUTOMATIC PROCESSES

Semi-automatic welding offers very interesting possibilities, in that high current densities giving high deposition rates are available; thus, it should be able to bridge the gap between manual electrode welding, where currents are limited and frequent stoppages to change electrodes are inevitable, and the fully automatic processes, where production quantities must be sufficient to justify the capital investment, and where seam lengths and access to the joint must be such as to allow rapid setting-up.

Semi-automatic welding has been widely used for some years for the welding of aluminium and other non-ferrous alloys by the argon-shielded bare-wire process, but although this process has been available for some three to four years for the welding of mild steel, no great progress has been made in its commercial application to general shop fabrication. Although it has been shown[1] that the process can give economic advantages if used on the correct type of work at a high duty cycle, its development has been limited by the high cost of the consumable materials—wires of special composition and argon/oxygen mixtures as a shielding gas. Attempts have been made to reduce this cost by substituting carbon dioxide shielding, but for semi-automatic operation this results in an unstable arc with heavy spatter, which reduces productivity because post-cleaning of the work, and frequent stoppages to clean the gas passages of the welding gun, are necessary.

Semi-automatic welding by the submerged-arc process has also been available for a number of years, but since the operator cannot see the deposited metal, the process has been restricted to skilled operators making a limited range of joints.

Leder[2] has shown that the limitations of shielding the arc either by gas or by flux alone can largely be overcome in processes in which flux and gas shielding are used in conjunction. In such a process, the gas protects the molten metal from the air and provides a suitable atmosphere in the arc region, whilst the flux supplies the necessary deoxidants and any alloying additions required. As a large part of the metallurgical control is derived from the gas, the flux can be designed to give good operational properties and easy deslagging. The arc is a visible one, and since the deoxidants are contained in the flux, expensive core wires of special composition are not required as in processes shielded by gas alone. Thus, a semi-automatic process operating on the flux/gas principle combines the use of cheaper electrodes, shielded by carbon dioxide, with high deposition speeds.

Development of flux/gas semi-automatic processes is along three lines, *viz.*, the use of flux-cored tubular electrodes, a bare wire with magnetic flux, or continuous covered electrodes, carbon dioxide being used as the gas shield in each case.

The flux-cored tubular electrode gives high deposition rates, of the order of 20 lb/hr at 500 amp on a $\frac{3}{32}$ in. dia. electrode, this high figure being due in part to resistance heating in the electrode extension from the contact tube in the welding gun. The process has not yet been developed for positional welding, but, on the other hand, the electrode construction obviously gives scope for variation in the composition of the flux core to cater for a range of alloy steels.

The magnetic flux process gives somewhat lower deposition rates, of the order of 15 lb/hr, but it can be used for positional welding although it appears that operator skill is an important factor.

The continuous covered-electrode process gives high deposition rates but is somewhat limited by the size and stiffness of the electrode restricting the manoeuvrability of the gun. It shows promise, however, on hard-surfacing applications, where readily available low-alloy steel electrodes can be used on surfaces which are easy of access.

FULLY AUTOMATIC PROCESSES

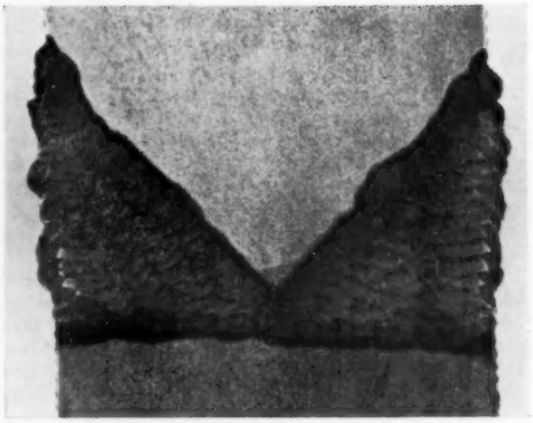
The two processes which are firmly established in the field of automatic welding are submerged-arc welding and welding with continuous covered electrodes with basic coverings.

Recently, carbon dioxide shielding has been applied to the continuous covered-electrode process to give better operational characteristics, the ability to make horizontal-vertical fillets, and greatly increased welding speeds, with deposition rates up to 35 lb/hr. Although this deposition rate can be exceeded by variations of the submerged-arc process, the greater tolerance allowed in plate condition and fit-up, and the fact that it gives a visible arc, make CO_2-shielded continuous covered-electrode welding more versatile for general fabrication.

The process readily lends itself to the welding of alloy steels, and electrodes are available for a range of low-alloy steels, creep resisting steels, 1% silicon transformer steel, etc. Normally, continuous electrodes with basic coverings for these steels are very prone to long-arc porosity, but this defect is readily overcome in the CO_2-shielded process. The process has also been used for the welding of horizontal-vertical butt joints in thick plate, and Fig. 1 shows the macrograph of such a joint in 4½ in. thick plate. This was made with a K-type preparation, with a 45° double bevel on the top plate only and a $\frac{5}{32}$ in. gap. Root runs were first made manually, using low-hydrogen rutile iron-powder electrodes. Automatic welding was then used, a few passes being made on each side alternately. When the runs had reached the outer edge of the bottom plate it was necessary to provide a ledge on which further automatic runs could be built up, and this was done by a further run of manual welding. Thus, the 34 runs comprising the outside runs and the two root runs of the joint were made manually, but the bulk of the weld metal was deposited automatically at 500 amp and a traverse speed of 24 in./min for each run.

With the demand for increased welding speeds, much attention is being paid to variations in the submerged-arc process which allow of high deposition rates. Parallel welding, *i.e.*, two wires fed through one welding head and powered from one power source, will give deposition rates up to 50 lb/hr, whilst multi-power tandem welding, *i.e.*, two wires fed by two welding heads and powered from two separate power sources, will give deposition rates up to 90 lb/hr.

A further variation of submerged-arc welding, termed 'electro-slag' welding, has also been used for vertical butt welding, and very high deposition rates have been claimed. In Britain, this technique has so far only been investigated experimentally, and it has yet to be confirmed that the general soundness and metallurgical quality of the deposit will be adequate for thick-walled pressure vessels, the application which offers the widest scope for the process.



1—Macrograph of horizontal-vertical butt joint in 4½ in. thick plate

Some use has been made of the bare-wire CO_2-shielded process in a fully automatic form for the welding of mild steel. The process does not compete with the established automatic processes in general fabrication, as deposition rates are comparatively slow, *e.g.*, 18 lb/hr, and consumable costs are relatively high; however, it can show advantages in applications where the very presence of a flux presents difficulties, *e.g.*, the welding of small-diameter components.

PART II—DEVELOPMENTS IN THE APPLICATION OF AUTOMATIC ARC WELDING PROCESSES

Automatic arc welding is automatic in the sense that it provides for the control by either electrical or mechanical means of the welding conditions; these include the position of the electrode relative to the work, the arc length, and the speed of movement between the electrode and the work. Accurate control of these factors makes for higher and more consistent quality of welding. The use of automatic apparatus for holding and propelling the electrode makes it possible to use very much higher currents than would be practicable in manual welding, and this is reflected in the greater metal deposition rates attainable with automatic welding. Furthermore, the use of a coil in place of a rod electrode reduces lost arcing time due to stoppages for change of electrode.

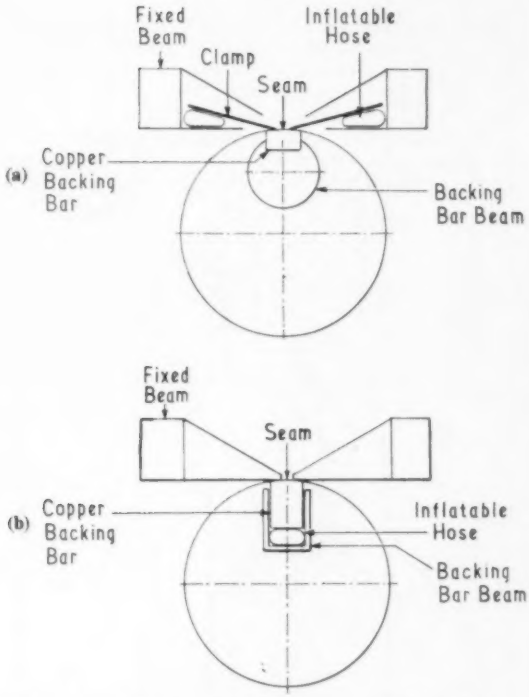
With the latest automatic welding processes, which have been referred to, metal deposition rates have become so high that the total arcing time for a welding operation is in many cases becoming small compared with the time occupied in handling and preparing the work or the welding machine; much thought has therefore been directed in recent years to means for reducing handling costs and increasing arc utilization, to enable the new welding processes to be used to the best advantage.

It is convenient to deal firstly with those automatic welding operations which involve bringing the work to the welding head, and secondly, with those where the welding head is more conveniently brought to the work.

REDUCING COST OF HANDLING AND PREPARING THE WORK

Backing bar jigs

All the machines illustrated in Figs. 2–4 have been designed to enable a full-penetration butt weld to be made between the edges of a pair of plates by means of a weld from one side only. They all embody a backing bar, usually of copper, inserted in the upper surface of a stiff beam on which the joint to be welded is laid. The beam is supported at its ends in the machine, and clamps press the two edges of the sheets down on to the backing bar. The welding head runs on some form of track parallel to the backing bar.

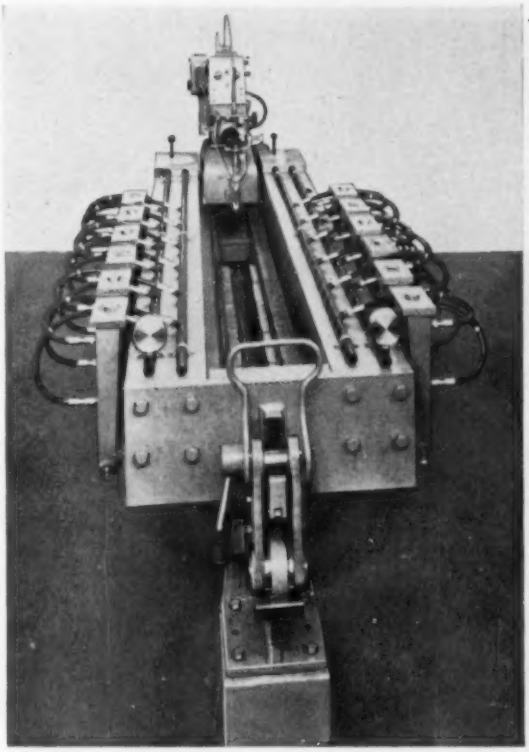


2—Operation of backing bar jigs: (*a*) expanding backing bar; (*b*) rigid backing bar

Backing-bar jigs vary in detail according to the thickness and shape of the sheets to be welded, but they can be divided into three main types which have been developed successively to decrease the work preparation time.

Expanding Backing Bar Jig—In this type of jig, the plate edges are clamped between fixed beams on the top surface and the copper backing bar, which is pressed upwards against the underside by hydraulic or pneumatic means, as illustrated in Fig. 2*a*. A jig of this type has been used for many years for welding the longitudinal seams of hot water cylinders made from 14 and 16 s.w.g. mild steel by the submerged-arc process.[3]

3—Rigid backing bar jig for welding lengths of strip off strip mill

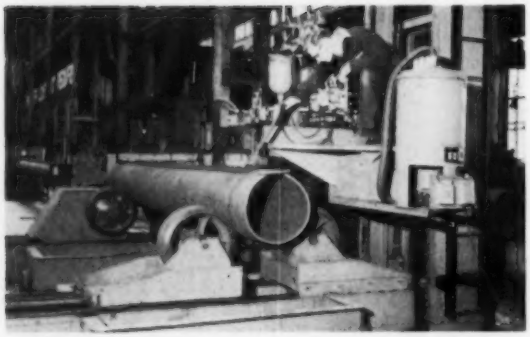


4—Backing bar press

It is necessary, with this type of jig, to tack the edges of the seam together before the cylinder is put in the jig; this can take substantially longer than the subsequent automatic welding. A more recent development of this jig makes tacking unnecessary.

Rigid Backing Bar Jig for Cylindrical Work—In this jig the backing-bar beam consists simply of a solid circular bar of steel, with the copper backing strip let into a slot in its surface. Clamps are positioned along the length of the upper beams on either side of the backing bar, the clamps on each side being operated independently. This arrangement (*see* Fig. 2*b*) permits the edges of the joint to be clamped one at a time. A guide is swung into position to ensure quick alignment of the first edge with the centre-line of the backing bar; as soon as this edge has been clamped, the guide is swung clear, and the second edge is presented against the first and clamped. The prior tacking operation is thus eliminated, and the guide mechanism greatly reduces the time taken to align the seam. A jig of this type is suitable for use with either the submerged-arc or the tungsten-arc process.

A similar type of backing bar, shown in Fig. 3, is used for joining the ends of lengths of strip coming off a strip mill. In this instance, the edge of the first end is located on the centre-line by means of retractable stops within the backing bar, which are withdrawn after the first end has been located and clamped. This rather



5—Welding of external longitudinal seam of pipe, using a conventional combination of traversing roller bed and cantilever welding head positioner

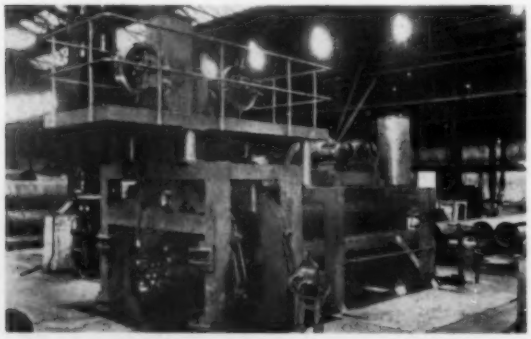
more complicated mechanism is justified in this type of machine, where the length of the whole welding cycle must be reduced to an absolute minimum.

Backing Bar Press—The machine shown in Fig. 4 is similar in principle to that in Fig. 3, and has been developed for the single-pass butt welding, by the CO_2-shielded continuous covered-electrode process, of plates up to $\frac{1}{2}$ in. thick. In order to ensure that plates of this thickness, which may not be flat when they are presented to the jig, are accurately aligned before welding, the clamping pressures must necessarily be much higher, and the load exerted by the clamps on this jig amounts to 5 tons per foot of seam on each side of the seam. This ensures that all initial waviness along the edges of the plate is pressed out. In addition, the backing bar is given a slight curvature so that, after the welded seam has cooled, the plate is dead flat.

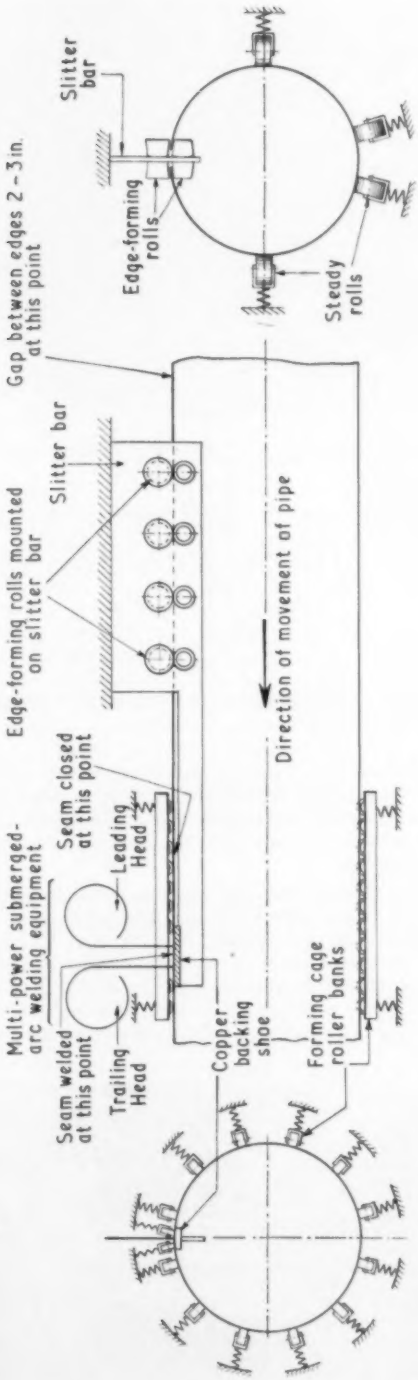
The use of a jig of this type eliminates not only tacking of the joint, but also the flattening operation which would otherwise be necessary before welding.

Pipe welding machines

Welding External Longitudinal Seams of Pipes—Figure 5 illustrates the conventional equipment for welding, by the submerged-arc process, the external longitudinal seams of any cylindrical vessel, and in the case of larger diameter vessels the circumferential seams too. With this equipment the seam must be tacked before welding, the edges being brought together by means of stirrups and wedges.

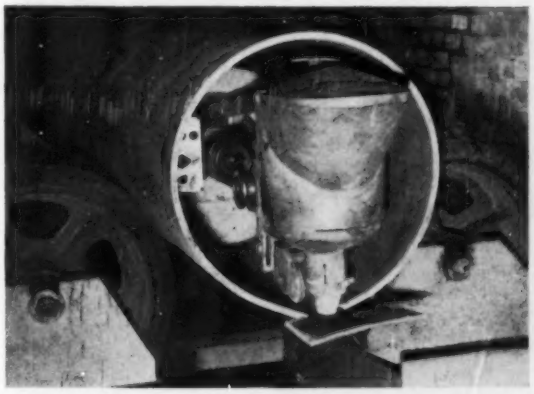


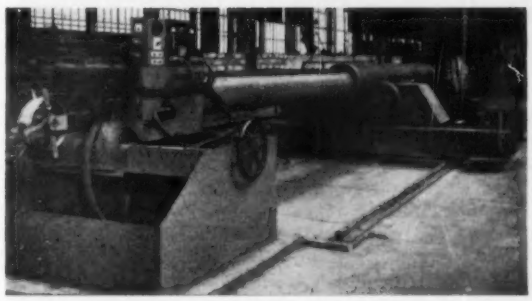
6—Continuous edge forming and seam welding machine, also showing unwelded skelps



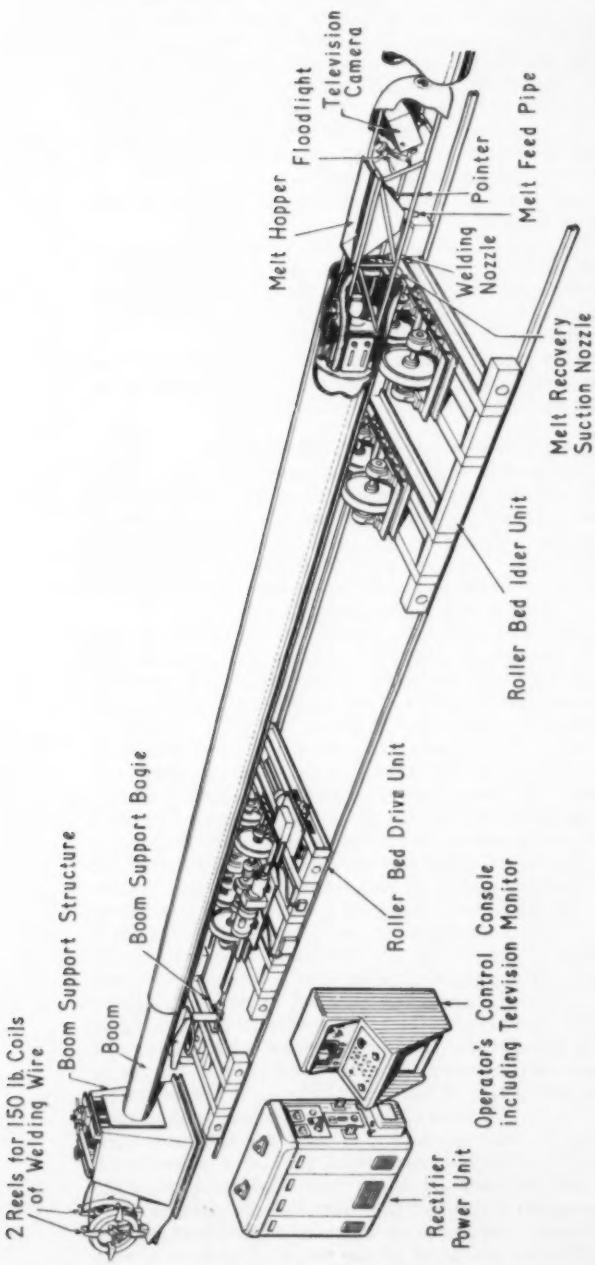
7—Arrangement of edge-forming rolls, welding equipment, and final forming cage on continuous edge forming and seam welding machine

The equipment shown in Fig. 6 is capable of welding the longitudinal seam in a pipe without prior tacking, and it will be seen that the skelps as presented to the machine do, in fact, have a gap of something like 2 to 3 in. between the edges of the plate. This machine not only welds the seam, but also forms the edges to the correct radius of curvature, thus eliminating the need for pre-forming the edges before rolling of the skelp. This process is illustrated in Fig. 7, which also shows how the pipe, after passing through the edge-forming rolls, passes under the welding nozzles and through a cage which corrects the circularity and axial straightness of the pipe; the copper backing shoe, which is presented under the weld to permit full penetration, is also shown.





8—Pipe welding boom with mechanically guided nozzle



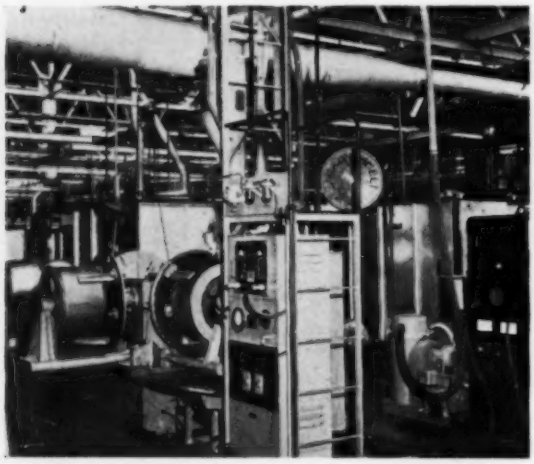
9—Pipe welding boom with television viewing of nozzle

With this machine the pipes are butted end-to-end and propelled through the machine in a continuous stream by means of a hydraulic ram. As a result, arcing is virtually continuous, so that the fitting of multi-power submerged-arc welding equipment is justified and full advantage is taken of the very high welding speeds possible with this process.

It is interesting to note that, in spite of the very high output of this machine (more than 2000 ft of $\frac{1}{2}$ in. thick pipe per 8-hour day), adjustment of the machine settings to suit different pipe diameters can be made in 2–6 hr, depending on the magnitude of the change in diameter.

Welding Internal Longitudinal Seams of Pipes—A welding boom is commonly used for the automatic welding of the internal seams of pipes of which the external seam has already been welded. This process is necessarily a discontinuous one, since the boom must be withdrawn from each length of pipe after the completion of the weld.

Figures 8*a* and *b* show a welding boom designed for pipes with internal diameters down to a minimum of 18 in. In order to retain the nozzle of the welding head in this machine over the centre-line of the seam, a small



10—Turret-type welding machine for vacuum brake cylinders

V-preparation is made on the inside edge of the plates, in which a guide wheel may run. The submerged-arc welding head is flexibly mounted on the end of the boom, so that the guide wheel is not prevented by stiffness of the boom from following the groove. The pipe to be welded is mounted on a traversing roller bed, the welding head remaining stationary during welding. Machines of this type are giving excellent service, but the introduction of the continuous external welding machine has necessitated a new approach to welding of the internal seams, in order to match more closely the output of the external machine.

The machine illustrated in Fig. 9 performs a similar operation, but the boom is equipped with television viewing equipment, the camera being located immediately forward of the nozzle, and the television screen mounted over the controls in the console at which the operator sits. The operator corrects the alignment of the nozzle with the seam during welding by the rotation of the roller bed on which the pipe is mounted. This equipment makes possible the welding of an internal seam in a small-diameter pipe without the provision of any mechanical guiding for the nozzle. There is no necessity for any V-preparation on the inside edges of the seam, and the machine can also be used to seal a full, or virtually full, penetration weld previously made from the outside. Parallel submerged-arc welding is used, giving a welding speed approximately 50% greater than the single-electrode welding used in the mechanically guided machine.

Turret type welding machines

Vacuum brake cylinders have been fitted to passenger coaches for many years, and the first automatic welding installation for the production of these cylinders in this country was designed in 1949. Whilst this was an efficient machine, which has produced tens of thousands of cylinders, the production problem was considered in a fresh light when British Railways decided to fit vacuum cylinders on goods, as well as passenger, traffic.

The fabrication involves welding a steel ring, 26 in. dia., 2 in. wide × § in. thick, in the open end of a deep-drawn 10 s.w.g. pressing, and with the early machine this was done as a separate operation, the ring being tack welded in position before loading on the welding machine.

The new machine design (*see* Fig. 10) was based on the principles of loading the pressing and ring as separate components, locating and holding them in correct relation to one another, and welding by submerged arc without prior tacking. Since for maximum welding speeds a close fit is required between the ring and cylinder, it was decided to include a small spigot on the ring as part of the normal machining operation. This serves the dual purpose of locating the ring accurately and providing a close fit when the ring is forced into the pressing. To minimize delay due to loading and unloading of the machine, it is equipped with four work-holding fixtures on a turret mounting. This arrangement also facilitates an easy flow of components to the machine and of welded cylinders away from it.

The entire sequence of the welding operation is initiated automatically once the operator has depressed the switch controlling the indexing movement. Starting is positive, with h.f. initiation, and the finish of the weld is controlled by a time switch.

This machine, which is typical of the modern conception of a welding machine tool for mass production, has an output potential of 40 units an hour.

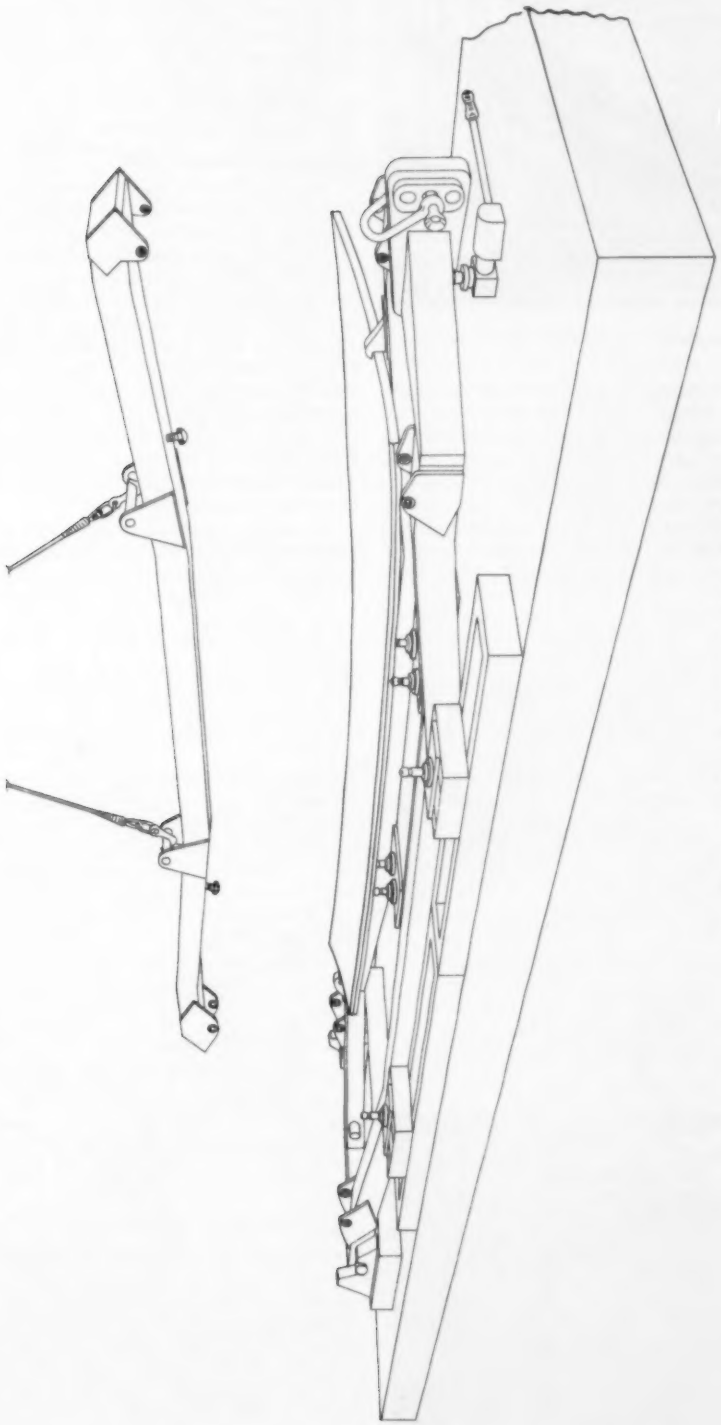
Welding of spherical segments for atomic reactors

The panels which form the components of a spherical atomic reactor vessel are usually assembled in pairs before erection, to reduce the amount of manual welding *in situ*. The equipment shown in Figs. 11–13 was designed to facilitate the handling during assembly, by multi-power submerged-arc welding, of these very heavy plates.

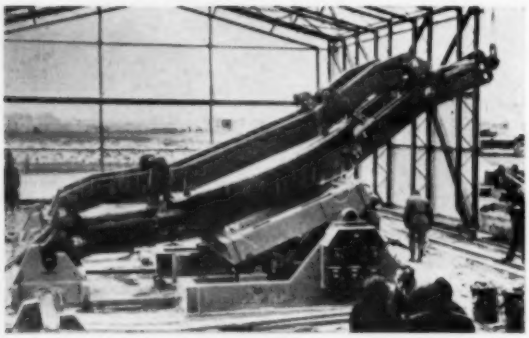
Figure 11 shows the two panels on the setting jig; this consists of a number of jacks on which the two panels are laid, the heights of the jacks being pre-set to ensure that the panels are positioned correctly with respect to each other. While in this jig, a number of manual root runs are put in the seam. To lift the plates on to the welding manipulator, they are held in a cradle, the lower section of which (the support cradle) is lowered between the jacks in the setting jig before the plates themselves are laid onto it, whilst the locking beams of the upper section are clamped on top of the plates and so serve to lock them in the support cradle.

The cradle with the plates is transported by crane to the welding manipulator, and is lowered into the pivot frame shown in Fig. 12. The cradle is allowed to fall back gently against the tilted table of the manipulator, to which it is then firmly attached by means of lugs on the support cradle. The cradle with the plates is tilted into position for welding by means of the hydraulic jacks on the manipulator, the pivot pins on the cradle end lifting free of the 'vee' blocks on the pivot frame.

Figure 13 shows the self-propelled multi-power welding machine, which is used for the multi-pass welding operation, and which runs on a curved track to suit the curvature of the plate. The rate of tilt of the manipulator is under the control of the welding operator, who can ensure by means of a spirit level that the surface of the panel at the point of weld is always horizontal.



11—Panel plates for spherical reactor in setting jig



12—Welding manipulator for spherical reactor panels

To balance the welding on either side of the joint, it is necessary at intervals to turn the plate over. This is done by removing the welding machine and tilting the manipulator so that the pivot pins on the cradle re-enter the 'vee' blocks on the pivot frame. The cradle is released from the manipulator table, hoisted by crane into a vertical position, lifted just sufficiently high to be clear of the machine, and rotated through 180° about a vertical axis. It is then allowed to drop back into the pivot frame and tilt over on to the manipulator table. Lugs on the locking beams, similar to those on the support cradle, enable the cradle to be re-attached to the manipulator table.

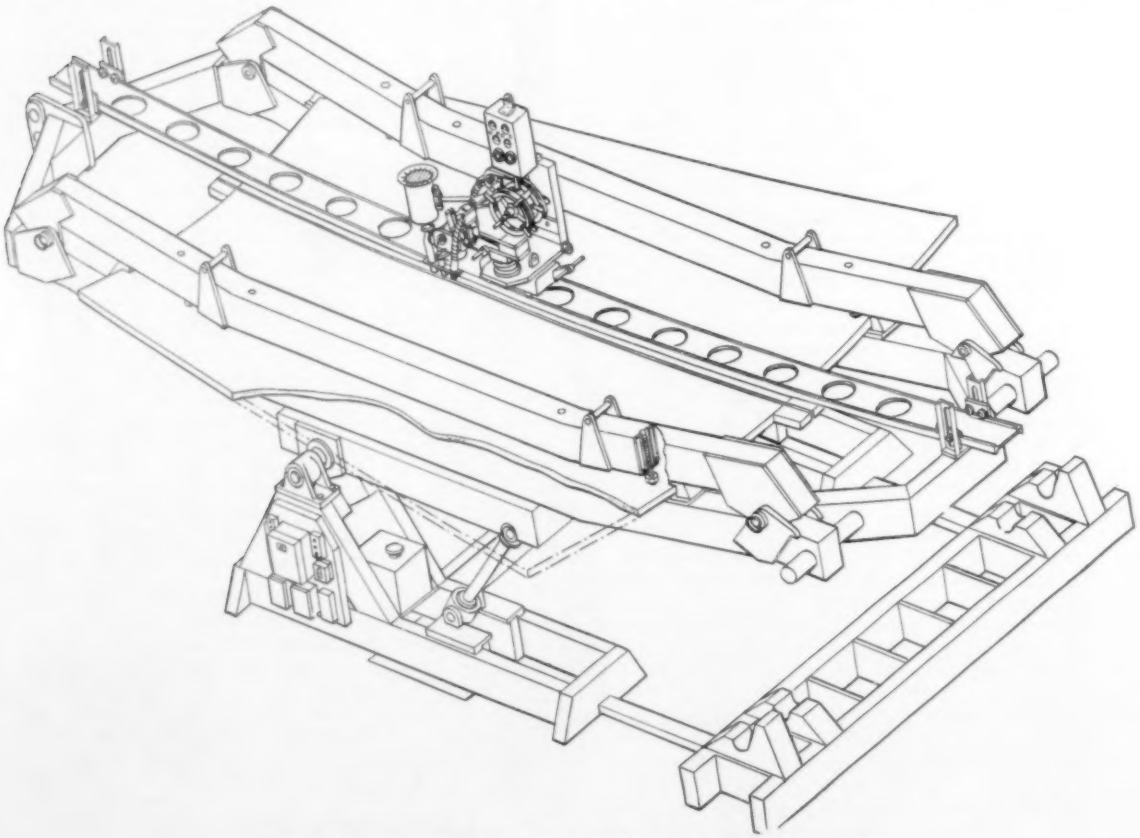
By means of such equipment these heavy plates can be handled rapidly and safely, so that high utilization of the multi-power welding machine is ensured.

Plate girder welding machine

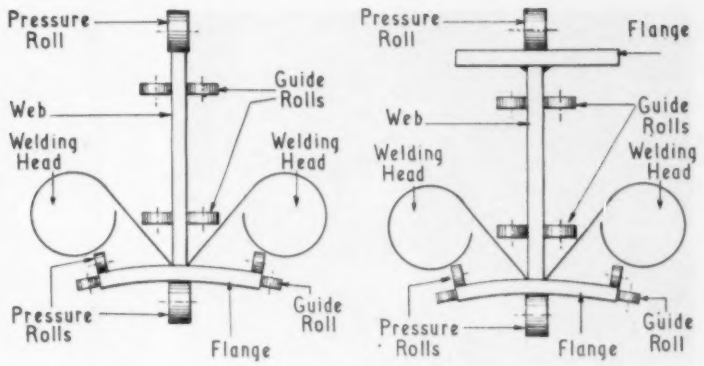
To illustrate the importance of assembly cost in the total cost of assembly and welding, it is of interest to consider the fabrication of a welded plate girder.

The web plate must be accurately set up along the centre of, and at right-angles to, each flange plate, and the plates must be held in this position while tack welds are made at close intervals along the whole length of the girder. Where it is essential to have a girder with truly flat flanges, it may be necessary to fit strongbacks before welding, which will apply a small pre-set to counteract the transverse shrinkage of the fillet welds joining the flange to the web. Where the plates have been stored out of doors, cleaning of the plate edges before assembly may be necessary, entailing another separate operation.

In all, the assembly time for a 50 ft long plate girder may total some 15 man-hours. The welding time, using two automatic heads operating simultaneously,



13—Manipulator for spherical reactor panels, showing multi-power welding equipment



14—Diagram of plate girder welding machine

may total as little as one hour, with one, or at the most two, welders. Obviously, the only way to make a really effective reduction in the time for fabricating such a girder is to cut down the assembly time. This might be achieved in part by using a separate assembly fixture, but a much more impressive reduction could be obtained by combining assembly and welding in one machine.

A very large and costly machine would be needed if welding were performed as hitherto with moving heads, and the components of the girder were clamped along its whole length. However, if the welding heads were kept stationary, the machine would be relatively simple and cheap, since it is only in the immediate vicinity of welding that the web and flange plates need be accurately located with respect to one another. A schematic arrangement (Fig. 14) shows the essential principles of such a machine.

The web and one flange plate would be welded first, and the **T**-section would be turned over and welded to the second flange plate in the same or in a second machine. All ancillary operations, such as edge cleaning and pre-setting, would be performed on the single machine, so that, effectively, all the man-hours previously spent on assembly would be eliminated.

So far, no machines of this type are in use in this country, but they would provide an ideal application for the CO_2-shielded continuous covered-electrode process.

INCREASING MOBILITY AND REDUCING TIME FOR SETTING THE WELDING MACHINE

In the case of all the machines referred to in the previous section, the machines and the welding heads are substantially fixed. However, where heavy workpieces are concerned, it is often more convenient if the machine is brought to the work.

Gantry type welding machine for assembly of stiffened panels

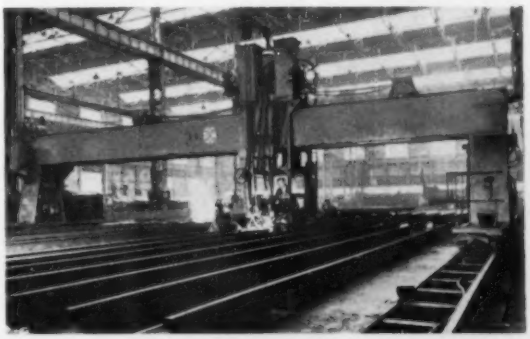
An example of such a machine is the gantry-type welding machine (Fig. 15) which has recently come into use in British shipyards for butt welding the plates in bulkhead panels and fillet welding the stiffeners to the panels and shell plates. This machine spans the working area, running on rails on either side of it, and a high-speed travel motion is used for positioning the machine at any point along the rails. The carriage, carrying the welding heads and sometimes the operator too, may be traversed across the width of the beam. When such a gantry is being used for butt welding, the welding can take place either parallel to the rails on which the gantry is mounted or parallel to the beam. In the first instance, the whole gantry is traversed at welding speeds; in the second instance, the carriage only is traversed at welding speeds along the beam. When this machine is equipped for fillet welding, welding normally takes place parallel to the rails, the cross traverse of the carriage being used solely for positioning the carriage at the end of each stiffener.

Where a single machine is to be used for both butt and fillet welding, separate welding heads are normally used for each process, as this avoids re-setting the heads each time the change-over is made.

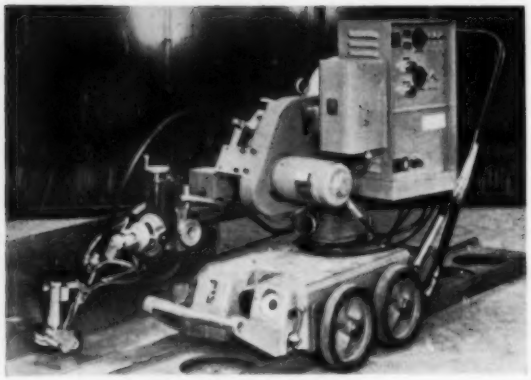
Gantry machines carry sufficient welding materials for several shifts of continuous welding, and because they carry their own power units there are no trailing cables. Primary power is supplied by means of collector brushes running on bus-bars, or by means of cable reels. The machine is thus entirely independent of the shop crane services.

As a result of these special features, the arcing time with such a machine is currently averaging between 50% and 60% of the operator's clocked hours, and in this instance the limiting factor on the arc utilization is the speed with which the panels and stiffeners can be prepared for welding. In the absence of this limitation a utilization of 80% would be entirely practicable.

Machines of this type have been equipped for welding by the submerged-arc, CO_2-shielded continuous covered-electrode, and argon-shielded bare-wire welding processes.



15—Gantry type welding machine



16—Portable welding machine

Portable self-propelled welding machine

Figure 16 shows a portable self-propelled welding machine with an argon-shielded bare-wire welding head. This machine was specially designed for use in the shipyards for the welding of aluminium superstructures. It may be used for either fillet or butt welding, and the change-over from one to the other may be made in a matter of minutes.

Much time can be taken up in moving such machines from one job to another, as they are too heavy for the operators to lift and may be difficult to man-handle over rough surfaces on their running wheels. This machine is designed to run on rails while welding, with the outer rubber-tyred wheels lifted just clear of the ground. As soon as the weld is completed, the operator declutches the driving wheels and pushes the machine off the end of the rails, so that it runs on the larger rubber-tyred wheels which are, of course, free. The machine may then be pushed round a deck or workshop floor by a single operator, even if the floor is not particularly level. A crane is only required where the machine has to be lifted across a space where there is no continuous platform.

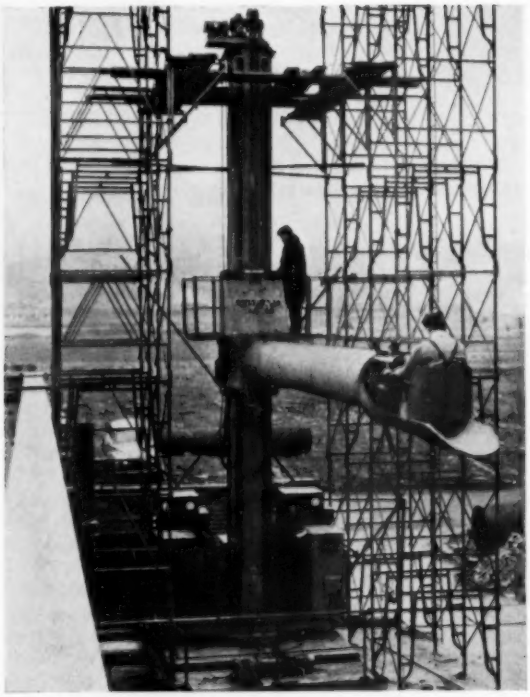
The use of a machine of this type greatly reduces the time normally lost in movement from one work-piece to the next.

Travelling welding booms

Such machines essentially consist of a bogie on which is mounted a vertical pedestal supporting a cantilever boom. In the case of the equipment shown in Fig. 17, multi-power submerged-arc equipment is mounted at the end of the boom. The boom is designed for running on the same rails as a traversing roller bed, which supports the vessel to be welded. The height of the boom on the pedestal is adjustable, so that the machine may be used for welding internal and external longitudinal and circumferential seams in vessels from 4 ft to over 20 ft in diameter. The boom can be pivoted about a vertical axis through 180°, so that it can weld vessels on either side of it.

Like the gantry welding machine, this machine carries its own power units and only requires the standard 440 V supply which may be introduced by means of either an underground bus-bar system or a cable reel.

The great mobility and versatility of this machine,



17—Mobile cantilever welding boom (the scaffolding surrounding the machine is that used for its erection)

and the speed with which it can be adjusted for welding in a variety of positions, ensure a much higher arc utilization than would be possible if separate machines had to be used for internal and external welding, and if movement of the machines necessitated the careful manoeuvring of long trailing cables.

CONCLUSIONS

The new automatic arc welding processes offer many advantages beside that of high metal deposition speeds but, none the less, increased output per man-hour or per square foot of floor space is usually the primary consideration governing their introduction. In order to obtain the highest economies with automatic arc welding it is clearly essential to provide for maximum arc utilization, by reducing handling, preparation, and setting-up time to a minimum.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. P. L. J. Leder for his criticism and advice, and to Mr. J. A. Lucey for many helpful suggestions.

They also wish to thank the following firms for making photographs available: Clayton, Son and Co., Ltd. (Figs. 5 and 8); Stewarts and Lloyds Ltd. (Fig. 6); The Austin Motor Co. Ltd. (Fig. 10); Whessoe Ltd. (Fig. 12); Harland and Wolff Ltd. (Fig. 15); The Motherwell Bridge and Engineering Co. Ltd. (Fig. 17).

REFERENCES

1. D. B. Tait: *Brit. Welding J.*, 1957, vol. 4, pp. 501–511.
2. P. L. J. Leder: *Ibid.*, pp. 274–281.
3. R. Gardener: *Welding Metal Fab.*, 1954, vol. 22, pp. 184–187.

AUTUMN MEETING, 1958

Experiments with Self-Guiding Welding Equipment for Aluminium

By J. E. Tomlinson, B.Sc., A.I.M., and R. V. Blewett, L.I.M.

THE paper describes the prototype of an automatically propelled welding machine operating on the 'self-adjusting arc' principle for use mainly for butt and fillet welding of aluminium in shipbuilding.

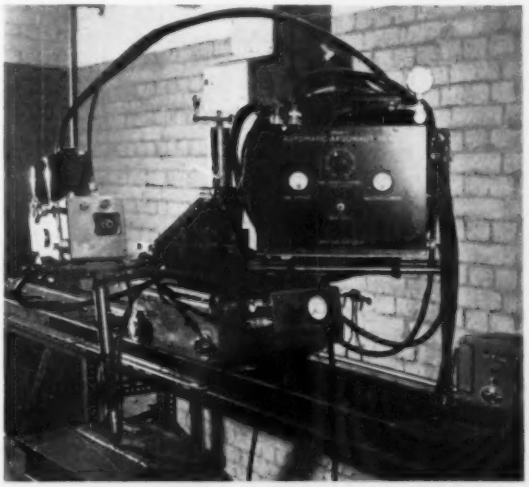
The machine is of light construction and can operate at high speeds without elaborate jigging and with the minimum of attention from the operator.

Three tables giving conditions under which the welding was carried out, using the prototype machine, are included.

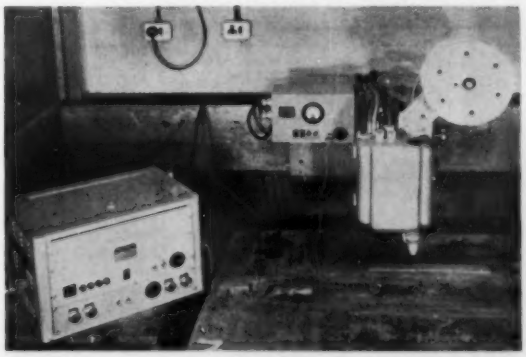
WITHIN six years of its introduction in Great Britain, manual inert-gas metal-arc welding of aluminium is a well-established and widely known procedure. It is noted for the high speed and ease of welding in all positions and for the good quality of deposited metal and freedom from problems of flux removal.

By any standards, it is a fast process so that mechanical traversing of long continuous joints is desirable, not only because it would reduce the demand on the concentration of the operator and would perfect the appearance of the deposit, but because it would allow more complete exploitation of the production potential. Additionally, the process is basically suited to automatic operation because there is no tedious mechanical matching of welding current and filler feed rate; the arc is self-adjusting.

Automatic equipment has been available for some time, the principal examples being the Argonaut Model C (Fig. 1) and the Sigma SWM3 (Fig. 2) units. Both these equipments work on the 'controlled arc' principle, in which the electrode feed rate is varied automatically as required to maintain a pre-set arc voltage (arc length), and hence are basically suited only for operation with constant current (drooping) characteristic power sources. In the Argonaut unit the electrode feed speed is controlled through two drive motors, one a.c. and one d.c. operated, working through a differential, whereas in the Sigma unit an electronically controlled single drive motor is employed. Both units are heavy and complex and appear to have been designed basically for shop operation, either as static installations where the work is moved past the head or mounted on booms on which they may be traversed over the work. As a result of trials in heavy industries, such as shipbuilding, with the units mounted on electrically driven tractors running on standard 10 in. tracks, it became apparent that some modifications to such equipment were desirable. For example, the welding of butts or fillets on cambered decking called for a rise and fall motion of the welding head; one solution to this problem, involving the construction of a fixed jig and traversing bed, has been



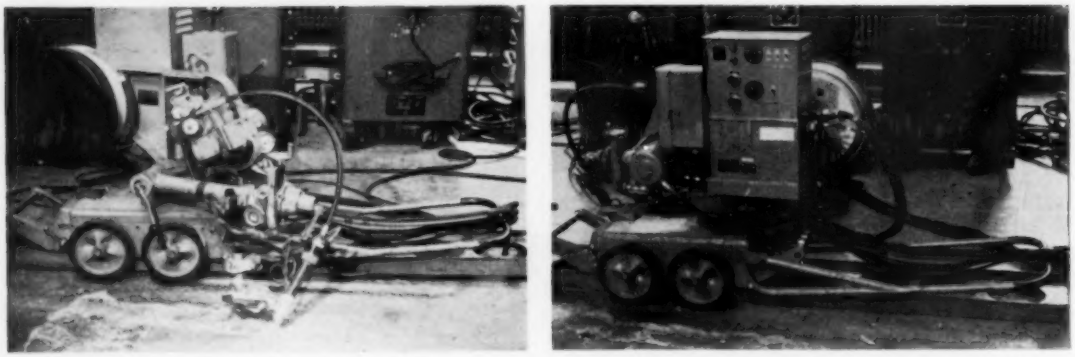
1—Automatic welding unit "Argonaut" Model C



2—Controlled-arc automatic welding head Model SWM 3 and control box. The head is mounted on a side-beam carriage with an electronic governor

Paper to be presented at the Autumn Meeting in London. Manuscript received 9th August 1958.

The authors are in the Research Laboratories of The British Aluminium Co. Ltd.



(a) (b)

3—Prototype self-guiding automatic "Sigma" unit after modification; (*a*) Nozzle side showing guide wheel; (*b*) reverse side showing control panel

described by Archbold.* Slight variations in the straightness of stiffeners, through initial twist or from distortion during welding, called for corrective action during fillet welding; these involved alteration to both the horizontal and vertical positioning of the head. Because of the high speeds of welding that can be attained, the operator must be in constant attention and must act quickly. Furthermore, unless the traversing track is aligned carefully and remains undisturbed and unless the plate edges are accurately cut, the operator is likely to have to re-align the head during butt welding operations. It has also been found that equipment which has proved successful in light engineering and chemical engineering work could profitably be re-arranged for heavier duties to give reduced weight, greater mobility, simplicity of construction and control, and versatility of operation, without dependence on the manual dexterity of the operator.

DESCRIPTION OF MODIFIED EQUIPMENT

With the above considerations in mind, a self-propelled welding machine having the following features was designed and manufactured:

(*a*) It operates on a self-adjusting arc principle so that the electrode feed speed can be preset and the current output of the power source will vary as necessary to maintain a constant arc length. With this method the equipment can equally well be operated with either a 'flat characteristic' power source or a conventional 'drooping' source. Thus the machine can be used with the wide range of existing power sources and, moreover, if required it can be modified for use in submerged-arc welding.

(*b*) It is designed for operation on standard 10 in. tracks. Numerous tests with tractors moving directly on the surface of aluminium plates have shown that, whilst self-guided fillets can be made, occasional skidding takes place and that when welding butts there is a tendency for the tractor to wander. The use of track is thus preferred.

(*c*) In addition to the normal rotational, horizontal, and vertical adjustments for the welding head, the head can be allowed to float conjointly with the self-guiding arrangement for both butt and fillet welding. The method of self-guiding with floating heads has been employed for some considerable time on gantry-type machines used for the fillet welding of mild steel by the submerged-arc and CO_2 shielded processes.

(*d*) It is relatively light and simple and is capable of being readily moved to a new operating position.

* H. D. ARCHBOLD: *Brit. Welding J.*, 1958, vol. 5, pp. 10–17.

The resulting equipment, which incorporates other features suggested by the experience of a number of users, is shown in Fig. 3. The welding head, electrode feed mechanism, and the control box are pin-mounted and can be locked securely in position or, for self-guided operation, can be left free to rotate. Although the electrode feed motor is not directly over the welding head, the feed of both $\frac{1}{16}$ in. and $\frac{3}{32}$ in. dia. N6 wire has proved most reliable. For example, in the welding of an experimental unit of superstructure, over 800 ft of butt and fillet welding was completed without a single operational burn-back. The standard SCC–1 control box contains simply a master on/off switch, switches controlling the supply of cooling water and argon shielding gas to the welding head, a switch controlling the tractor, buttons for inching the electrode wire up and down, an inching speed control useful for giving a fast threading speed and a low adjustment speed, an electrode feed speed control, and an on/off welding switch, which also operates the tractor motor. All cables from the control box and welding head have been secured to fixed points, such as the handle at the end of the tractor, so that they do not drag on the feed unit and interfere with rotation. In the free condition, the head and control box can be swung round by the lightest pressure from one finger.

The welding head, which is a combination of components from the standard HW11 and HW15 heads, is carried at the end of an arm, which can either be fixed for conventional working or released by the handle for self-guided operation. Under the latter condition, the arm is supported off the work by the appropriate guide wheel assembly. At the end of this arm there are the conventional horizontal and vertical traverses, but immediately beyond these there is a quick-action universal mounting, which is a most valuable aid to rapid positioning. Originally, the current relay was fitted to the arm carrying the welding head, but as this interfered with the free operation of the locking handle, it was refitted behind the electrode reel where there was ample room. The tractor on which the equipment is mounted is type HW1000, with two speed ranges, 8–100 in./min and 60–200 in./min, available simply by switching. Repeated trials showed that the lower range should not be used for speeds over 60 in./min, for above this value the speed was excessively sensitive to load.

The manufacturers fitted the tractor in a 'perambulator' frame, with wheels that are free above the plating when the tractor is on the traversing track. For re-positioning, the whole unit is simply pushed off the end of the track and is moved to its new position on the large rubber tyred wheels of the perambulator. The perambulator handle originally rose at an angle of 45°, but this prevented the whole assembly from being rotated on the pin joint through 360° which, as will be seen later, is a most useful feature in fillet welding. Accordingly, it was made possible to drop the handle into an almost horizontal position while the equipment was on a traversing track.

The power, water, and argon cables are bound together from their location at the handle of the tractor for a distance of 25 ft., after which individual cables go to the various supplies. This tidying-up and careful positioning of the incoming path of the cables has led to a simplification of operation and a reduction in interference with other nearby operations.

Electrode wire

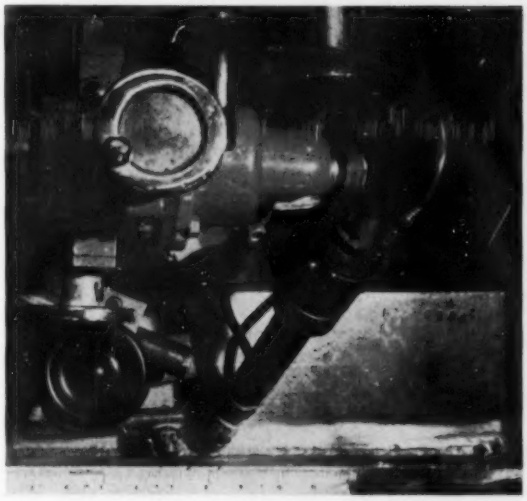
The equipment will accept not only the standard 10-lb reels of wire, but also 30-lb reels, which are of particular advantage with automatic units because replacement time is reduced and the extra weight on the equipment is no penalty.

The cost of electrode wire increases with decrease in diameter, and every endeavour has been made to deposit the whole range of single pass fillets from $\frac{1}{4}$ to $\frac{3}{8}$ in. leg length, using the less expensive $\frac{3}{32}$ in. dia. wire. But tests with this equipment have shown that though it is readily possible to lay single pass fillet welds from $\frac{3}{16}$ to $\frac{3}{8}$ in. leg length and to make butt joints in plate from $\frac{3}{16}$ in. thick upwards using $\frac{3}{32}$ in. dia. wire, $\frac{1}{16}$ in. dia. wire must be employed for $\frac{1}{4}$ to $\frac{3}{16}$ in. leg length fillets, or laps, such as those used to seal butt backing stiffeners to plating.

SELF-GUIDED WELDING OF FILLETS

In applications such as ships' superstructures, fillet welding predominates, and as the work is essentially repetitive, it is a natural target for automation. Unfortunately, fillet joints require accurate positioning of the welding head to achieve the correct weld profile, and any misalignment of the track or variation in the positioning of the stiffener can produce difficulties. Because of the small amount of metal that is required to be deposited per unit length of run, fillet welding is particularly suitable for high speed operation; this makes any alteration of the alignment of the head during welding a difficult matter. Where there is enough work, a bed may be laid down to support the plates, and over which the welding unit traverses, but there are many instances when this solution cannot be justified yet which call for some form of mechanization. It is in such cases that self-guided operation may prove advantageous, as it has done in the fillet welding of stiffeners to panels in steel construction.

The final form of guiding arrangement for fillet welding is shown in Fig. 4. Fixed to a bracket on the main arm is a tubular member carrying at its far end a 'toe-in' wheel which rests on the plate surface, and a 'push-off' sphere which bears on the web of the stiffener that is to be attached to the plate. The height of the whole guide assembly relative to the welding head



4—Plan view of arrangement for self-guided fillet welding

can be adjusted at the bracket on the main arm and by a knob on the top of the pillar supporting the 'toe-in' wheel. The horizontal and vertical position of the 'push-off' sphere can be adjusted at the point where the rod carrying the sphere is clamped to the 'toe-in' wheel assembly. Originally, a larger tubular member was used to carry this assembly, but it proved to be unnecessary and unsuitable for butt joints. With the 'push-off' wheel originally fitted, care had to be taken to ensure that its axis of rotation was truly vertical; the simple spherical fitting was therefore adopted. This had the additional advantages of being smaller and so reducing the risk of the assembly fouling the flanges of certain sizes of stiffeners, and also of proving self-cleaning with respect to spatter and fume. Some difficulty was at first experienced with jolting of the 'toe-in' wheel by spatter lying on the surface of the plate, but this has now been prevented by the fine wire brush mounted immediately ahead of this wheel. It is important that the wires comprising this brush should not be too stiff, otherwise they will affect the course of the wheel. The direction of motion of the tractor is always arranged so that the arm carrying the welding head and guide assembly is in a trailing position; on aluminium plate a 'toe-in' angle of 3–5° is adequate for most work.

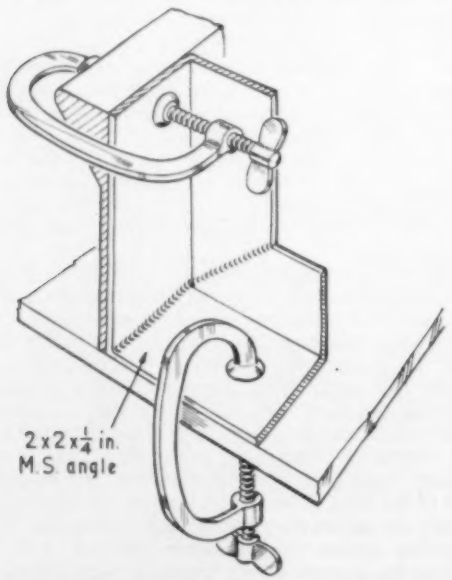
With this guiding assembly it is possible to deposit fillets lying as little as 3 in. away from the plate edge. This should be satisfactory for most applications, but the margin could be reduced to 2 in. should the need arise. To ensure that the welding head accurately follows any variation in alignment, it is essential to place the 'push-off' and 'toe-in' devices as close as possible to the welding head, both in a fore and aft and in a vertical and horizontal sense. The latter is particularly important, so as to minimize any misalignment of the head if the web of the stiffener should not be truly normal to the plate surface. In practice, these objectives appear to have been attained, and the machine has deposited long lengths of weld absolutely unattended.

Setting-up for fillet welding

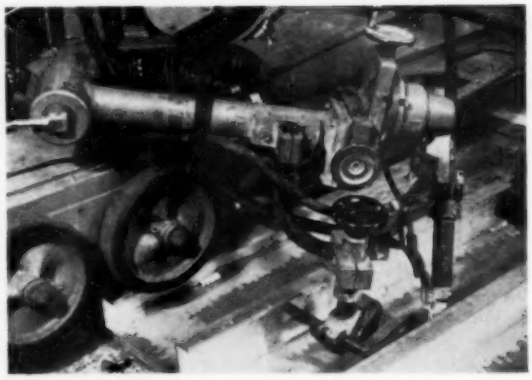
For the welding of stiffeners to plate no jigging is necessary. The stiffeners are simply placed on the plate surface if they are of the type with a small (butt-backing) table which will be lap welded to the plate, or supported by elementary brackets (Fig. 5) if they have no table and are to be fillet welded on. The latter type is more economic as it is 7–15% lighter than the corresponding size with a table (which is almost valueless in positions where it is not used to back a butt). The angular distortion occurring with the two types is the same. One slight defect of the flangeless stiffener is that there is a risk of undercutting, but this is not marked and is unlikely to be an overriding consideration.

The stiffeners are then tacked using $\frac{1}{2}$–1 in. tacks at 24 in. intervals; the tacks on one side alternating with those on the other. Tacking is usually carried out with manual equipment, but when a 'flat' characteristic power source is available, the automatic equipment can be used. Earlier automatic equipment was undoubtedly too unwieldy for such a purpose. If necessary, the machine will weld over tacks, generally without difficulty, and shipyard trials confirm that this is a practical operation.

With the conventional layout of some types of earlier automatic equipment, it was impossible to weld stiffeners spaced closer than 31 in., but with this new type, the minimum spacing has been reduced to 27 in. if only one run is to be made from each track position. Where the stiffener spacing is at 33 in. centres or more, the track can be positioned centrally, and at the end of one run the welding arm can be raised and locked and the whole unit rotated through 180°, so that a second run on the adjacent stiffener can be made without repositioning. With simple spacer rods, it is possible to locate the track correctly to $\pm\frac{1}{8}$ in., which is more than adequate, for the head will follow a weld line accurately with the track 3 in. out of line over a length of 20 ft. Where the stiffener spacing is less than 27 in., but not less than 7 in., double fillet or lap welds can be made by bringing the welding arm over the stiffener, as shown in Fig. 6.



5—Elementary brackets for jigging beams before tacking



6—Arrangement for welding stiffeners at spacing less than 27 in. but greater than 7 in.

When the track has been roughly positioned along the weld line, the next step is to check that the angles between the head and the work are correct. The angle in the plane normal to the line of the weld is important from the aspect of weld profile and undercutting, and a value of 45–47° to the plate surface is preferred. The angle in the plane of the weld line is also important, for with the head pointing in the direction opposite to that of motion (trailing angle) the deposit tends to be excessively convex and to be covered with a heavier black oxide dust. On the contrary, if the torch is pointing too far forward in the direction of traverse, holes may result in the deposit and the black oxide dust will also be formed. Experience has shown that a forward angle of 10–15° to the vertical is the most effective inclination on this equipment to obtain a good weld profile and a good clean deposit.

SELF-GUIDED BUTT WELDING

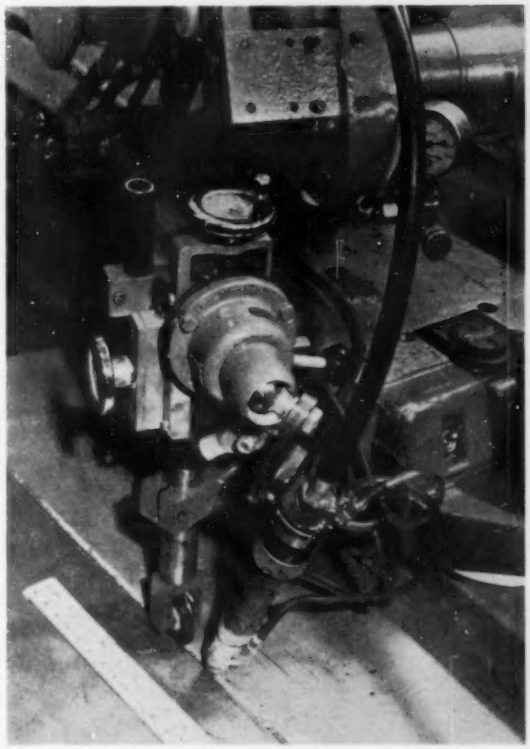
The features required for self-guided operation during butt welding of cambered deck plating are common with those of fillet welding; *viz.*, the torch must have controlled movement in both vertical and horizontal directions. To satisfy these requirements, the self-guiding gear for butt welding consists of a free running castor wheel, about $2\frac{1}{2}$ in. dia., which is also free to rotate about its vertical axis and which is mounted on an adjustable bracket similar to that carrying the fillet guiding attachment. The height of the arm carrying the welding head may be varied by a locking slide adjustment on the castor attachment, thus allowing the arm to be raised if necessary to reach over an adjacent stiffener or similar obstacle, that would otherwise impede the welding head.

The guiding is achieved by the castor wheel, which runs along the vee groove or open square-edge preparation of the plates to be welded. As with fillet welding, the self-guided bracket is in the trailing position, but the guide wheel is in advance of the torch (Fig. 7). To reduce lateral wander of the torch, it is essential that the guide wheel should be a good fit in the groove, and with this in mind two guide wheels have been designed for running in the most common edge preparations

used in the butt welding of aluminium. For welding plate of thicknesses greater than 0·312 in., using a permanent backing, the open vee preparation is recommended, and therefore the thick guide wheel with 90° included angle and $\frac{3}{16}$ in. wide tread is used, so that the angled sides of the wheel run along the edges of the vee groove in the plate (Fig. 8*a*). The apex of the vee of the guide wheel has been removed to allow the wheel to pass more freely over any tacks that may be required in the groove and also to permit the wheel to run in the groove after the first pass has been laid. For open square and close vee preparations, the narrow 60° vee wheel is used, to ensure that the wheel rides well down in the groove and does not tend to run out (Fig. 8*b*).

The self-guiding equipment is most efficient in single pass butt welds, but if two or more successive passes are to be deposited in the same groove, the self-guided equipment may still be used if there is sufficient depth of unfilled groove in which the guide wheel may run without danger of riding out. For this purpose, the wheel with the radiused tread may be used if the first pass has slightly overfilled the groove (Fig. 8*c*). Alternatively, the danger of tracking out may be overcome simply by locking the pivot which allows horizontal rotation, so that the welding head is still free to rise and fall with the deck camber, but so that lateral movement is restricted. It is, of course, necessary to align the track parallel to the butt joint, and this may be done quickly and simply by the use of spacing rods. The operator has then only to make slight lateral adjustments by use of the cross-slide mounted at the end of the boom. Sometimes difficulty is experienced in certain assemblies where tack welds have been used to hold the plates in position for welding, when there is a tendency for the welding head to wobble excessively as the guide wheel passes over the tacks. This trouble can be reduced by skimming the surface of the tacks with a pneumatic chisel, but if large tacks are required—for example, to hold down a distorted plate—the guide wheel may be allowed to run on the surface of the plate next to the weld, while the pivot allowing rotary movement of the arm is locked, as previously described. While this latter arrangement does not give fully self-guided operation, it does mean that the operator need only concentrate on making slight lateral adjustments if required to keep the torch on track, instead of having to make corrections in two planes simultaneously.

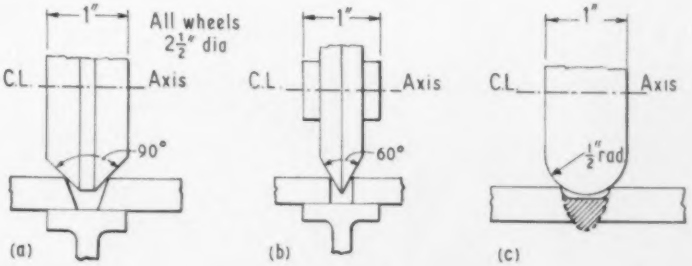
The recommended technique for tacking butts which are backed permanently on deck beams, girders, or stiffeners, or temporarily on aluminium backing



7—Arrangement for self-guiding during butt welding of grooved plate

strips, is to place 1–2 in. tacks on alternate sides of the backing at approximately 9 in. intervals. The tacks should not be more widely spaced as there would be a tendency for the plates to rise up from the backing to produce a gap between the backing stiffener and the plate. This gap would create difficulties in subsequent seal welding and could also cause the plate surfaces to be misaligned. For butt welds without backing the tacks may be placed on the upper surface of the plate, but it is recommended that a high current be used to ensure that the tack weld gives good penetration, so that the surplus reinforcement may be skimmed off to assist the easy passage of the guide wheel over the tacks.

Close square-butt preparations cannot be welded with the self-guided attachment unless a small sighting



8—Profiles of various guide wheels for self-guided butt welding; (*a*) Open-vee edge preparation; (*b*) narrow open square or vee preparation; (*c*) for 2nd or subsequent passes in shallow but wide grooves

Table I

Laboratory conditions for fillet welding with SIGMA self-guided equipment (rectifier power source*)

Measured Leg Length, in.	*Open Circuit, V*	*Arc Voltage, V*	*Welding Current, amp*	*Traverse Speed, in./min*	*Wire Dia., in.*	*Argon Flow, cu.ft/hr*	*Nozzle Size*	*Torch Angle Side*	*Torch Angle Forward*
$\frac{3}{16}$	55	20	350	90	$\frac{3}{32}$	45	10	45°	15°
$\frac{3}{16}$	55	20	345	65	$\frac{3}{32}$	45	10	45°	15°
$\frac{1}{4}$	55	21	345	40	$\frac{3}{32}$	45	10	45°	15°
$\frac{1}{4}$	55	21	345	25	$\frac{3}{32}$	45	10	45°	15°
$\frac{3}{8}$	55	23·5	380	18	$\frac{3}{32}$	45	10	45°	15°

* B.O.C. type CDR425

groove is applied for the wheel to follow, but this must be deep enough to prevent the wheel from riding out, and in most instances it would be better to lock the horizontal movement of the arm and to limit the self-guiding to the vertical direction only, with manual control over the lateral movement.

For welding butts on cambered plates the track is chocked up firmly and the welding head is given a forward inclination not exceeding 15°. The nozzle of the head is approximately $2\frac{1}{2}$ in. behind the guide wheel and, ideally, the closer the wheel is kept to the nozzle the more accurate is the guiding, although there is a greater risk of the wheel becoming overheated and fouled with spatter. During long runs, the wheel has become very hot and has tended to seize-up, but this can be prevented by suspending a small woven asbestos apron between the torch and wheel, possibly aided by the use of an Invar wheel and axle.

POWER SUPPLY

No difficulty is experienced in starting, using a constant potential power source, and it is not necessary to clip the end of the wire after each weld, even with $\frac{3}{32}$ in. dia. wire. With drooping characteristic power sources there is some uncertainty over starting at the lower currents when $\frac{3}{32}$ in. dia. wire is employed, though this can be overcome by ensuring that the electrode is clipped to a sharp point.

It has been found that the best results are obtained when the control box, wire drive motor, and tractor motor have been running for a few minutes so that they are warmed up slightly. It is recommended that while other preparations are being made, such as setting up the self-guiding head, track, and so on, the tractor should be switched on at full speed with the clutch disengaged, and that the wire drive motor should be turning at full speed with the rolls slackened off so that no wire is fed through. The latter can be done either by depressing the inching button or by closing the weld start switch with the welding cable disconnected from the power source.

RECOMMENDED WELDING CONDITIONS

Fillet welding

Tests under laboratory conditions have shown that self-guided fillets ranging from $\frac{3}{16}$ to $\frac{3}{8}$ in. leg length can be deposited in one pass at speeds ranging from 55–100 in./min for the smaller sizes to 18 in./min for the $\frac{3}{8}$ in. fillets (Table I). However, under actual shipyard conditions, in which the open-circuit voltage is constantly fluctuating owing to varying loads on the input side, and where there is sometimes imperfect fit-up of some of the stiffeners to the plating, it has been found that welding speeds of about 30–50 in./min are more reliable in giving a good quality deposit free from irregularities. Details of the conditions used in a shipyard for welding part of an actual ship's superstructure incorporating a cambered deck are given in Table II. The speeds were somewhat lower than those achieved in the laboratory, but it is considered that although the speed of welding on the superstructure could have been increased slightly, it was more prudent to sacrifice some speed to ensure a sound deposit than to weld at the maximum speed only, and so lose time on subsequent local back chipping and repair welds.

The wire feed settings have been omitted from the tables, as the original potentiometer controlling the wire feed has been replaced by an experimental one of different resistance and, therefore, the settings cannot be related to any other SCC–1 control box setting.

It is widely appreciated that the cost of making a nominal size of fillet weld manually is determined to a significant extent by the size of fillet that is actually made. Mechanical traversing offers a means of controlling this variable, for the size of weld is then determined by the ratio of the pre-set electrode wire feed speed and the traversing speed of the tractor. Control of size will not be quite complete because of variations in fit-up (these should be slight with this kind of joint) and variations in the welding current (or, with a constant potential power source, the open-circuit voltage), which will cause some change in the

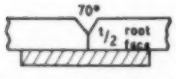
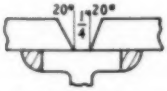
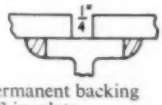
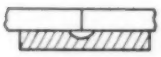
Table II

Certain shipyard conditions for horizontal/vertical fillet welding with SIGMA self-guided equipment

Measured Leg Length, in.	*Open Circuit, V*	*Arc Voltage, V*	*Welding Current, amp*	*Power Setting*	*Traverse Speed in./min*	*Wire Dia., in.*	*Argon Flow, cu.ft/hr*	*Nozzle Size*	*Torch Angle Side*	*Torch Angle Forward*
$\frac{3}{16}$	30	24	340–350	9	50	$\frac{3}{32}$	65	10	46°	15°
$\frac{1}{4}$	30	24	340–350	9	40	$\frac{3}{32}$	65	10	46°	15°
$\frac{1}{4}$	30	24	340–350	9	30	$\frac{3}{32}$	65	10	46°	15°

Table III

Certain shipyard conditions for butt welding with SIGMA self-guided equipment

Joint Configuration	*Open Circuit, V*	*Arc Voltage, V*	*Power Setting*	*Welding Current, amp*	*Traverse Speed, in./min*	*Wire Dia., in.*	*Argon Flow, cu.ft/hr*	*Nozzle Size*	*Torch Angle, Forward*	*No. of Passes*
 Temporary Al or steel backing bar. 0·4 in. plate	29·5	24	9	325	20	3/32	60	10	15°	1
	30	24·5	10	350	24	3/32	60	10	15°	2
 Permanent backing. 0·4 in. plate	35·5	26	11	355	20	3/32	60	10	15°	1
	35·5	26	11	355	20	3/32	60	10	15°	2
 Permanent backing 0·3 in. plate	29	24·5	9	365	30	3/32	60	10	15°	1
	28·5	24	9	330	30	3/32	60	10	15°	2
 Temporary steel or Al backing bar 0·26 in plate	30	25	9	355	30	3/32	60	10	15°	1
Temporary steel or Al backing bar. 0·18 in. plate	27	22·5	6	330	45	3/32	60	10	15°	1

spatter loss and weld profile. From this standpoint a fine and reproducible control of the wire feed rate is essential, and a feed speed indicator should prove helpful. There is also much to be said for the incorporation of an ammeter in the control panel, for the present practice of fitting the ammeter to the power source is inconvenient when the latter is some distance from the site of welding operations, as is almost always the case in shipbuilding.

Butt welding

Examples of conditions used in the shipyard for welding various plate thicknesses and joint configurations on both flat and cambered decking are given in Table III. The welding was carried out in a large prefabricating shop, which was open to strong gusts of wind, and it was found that the argon flows were quite adequate for most of the welding, although there were occasions when it was necessary to erect some form of wind break to prevent the argon being blown away.

CONCLUSIONS

Though further improvements will no doubt be made, it would appear that equipment of the type described will find a useful place in heavy engineering workshops where aluminium is to be welded. It enables both butt and fillet joints to be made at high speed without elaborate jigging and with the minimum of attention from the operator. Furthermore, the automatic welding of simultaneously cambered and curved surfaces has been proved to be a practical proposition.

ACKNOWLEDGMENTS

The authors wish to thank Quasi-Arc Ltd., Bilston, for producing the prototype machine described in the paper and to acknowledge the helpful suggestions made by Harland & Wolff Ltd., Belfast; by Vickers Armstrongs Ltd., Barrow, and by other experienced users of automatic welding equipment. Acknowledgment is also made to the Directors of the British Aluminium Co. Ltd. for permission to publish this paper.

AUTUMN MEETING, 1958

Welding of Some Creep Resisting Steels

By J. F. Mercer, A.I.M.

SYNOPSIS

THE development of higher temperatures and pressures for steam raising equipment has created a demand for steels having superior creep ductility and low creep rates, with consequent need for suitable electrodes for welded fabrication.

The paper describes the development of alloy electrodes for three types of Cr–Mo steel, which provide satisfactory weld metal deposits.

Introduction

THE welding of steels for service at elevated temperatures has become a highly developed and specialized branch of the welding industry which has expanded considerably during recent years. Progress in the design of steam raising equipment and electrical generators has demanded the use of higher temperatures and pressures. This progressive increase in steam temperature has meant greater efficiency and fuel economy with a higher yield in terms of kW per ton of fuel consumed. Recent developments in the petroleum industry have also called for the use of higher operating temperatures and pressures. It will generally be conceded by those directly concerned with the development of modern power plant that this progress has been greatly aided by the extensive use of welding and the evolution of refined welding techniques capable of yielding welds suitable for the most arduous service conditions.

Without discussing the mechanism of creep in detail it can be stated that a metal intended for use at elevated temperatures should possess two important features: (i) a low creep rate, *i.e.*, the elongation from creep at the service load and temperature should be low; and (ii) good creep ductility, *i.e.*, there should be no danger of a sudden failure because of an undue loss of ductility when the metal has been exposed to conditions of creep for an extended period.

The relative importance of these two factors is determined to some extent by the intended application of the material. Thus, for precision operation, such as turbine blading, creep rate is important, since good ductility is of no value if the elongation in service is sufficient to result in fouling of the casing by the blades. On the other hand, for high-pressure steam transmission, some expansion of the pipes over the years would be permissible, and creep ductility adequate to cope with sudden load fluctuations becomes an important factor. It may be argued that, for weld metal, creep ductility is the predominant factor. The volume of the weld is small when compared with that of the complete weldment and a creep rate which, in the parent plate material, would increase the dimensions of a vessel considerably after a number of years of service could be tolerated in the weld metal without any appreciable dimensional affect. It is vital, however, to ensure that the creep ductility of the weld metal is comparable with that of the parent plate. Any failure of the weld metal caused by undue loss of ductility during service would be a serious matter.

Paper to be presented at the Autumn Meeting in London. Manuscript received 24th July 1958.

Mr. Mercer is a member of the Research Dept. of Murex Welding Processes Ltd.

½% MOLYBDENUM STEELS

The first step towards higher temperatures and pressures was taken when the plain carbon steel in general use for steam raising and transmission equipment was replaced by steel containing ½%Mo, which allowed steam temperatures to be raised above the previous maximum range of 454–482°C. (850–900°F.). By this time welds of good radiographic quality and reasonable physical properties were being obtained by careful attention to welding procedure and electrode selection. It was considered that the addition of ½%Mo to the weld metal would result in welds having the desired creep properties. This addition presented no undue difficulty to the electrode designer, the transfer of molybdenum across the arc being reasonably easy and reliable. The physical properties of the deposited weld metal were not adversely affected, and the tensile strength was not raised unduly. Table I shows the relative physical properties of deposits made from two types of electrode with and without molybdenum.

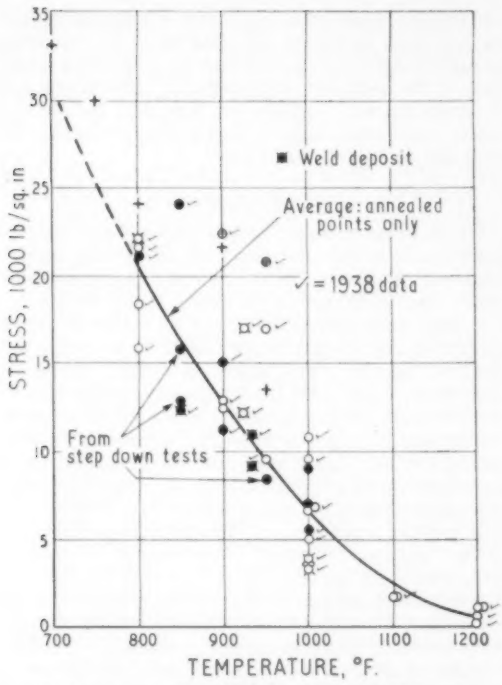
Table I

Physical properties of weld deposits from Mo-containing electrodes

	Electrode type			
Property	*E319**	*E319+0·5%Mo*	*E439†*	*E439+0·5%Mo*
U.T.S.,tons/sq.in.	34·0	36·5	30·5	33·5
Yield,tons/sq.in.	30·5	32	27	31
Elongation, %	29	28	34	32
Red. in area, %	60	58	65	64

* C, 0·07%; Mn, 0·35%; Si, 0·10%

† C, 0·09%; Mn, 0·40%; Si, 0·05%



1—Creep properties of ½%Mo steel and weld deposit
(Creep rate 1% in 100,000 hr)

The creep resisting properties of ½%Mo weld metal were also found to be satisfactory.[1] Figure 1, reproduced from the A.S.T.M. report on the elevated temperature properties of Cr–Mo steels, shows that the creep rate of the weld metal is comparable with that of the base material.

Carbon-molybdenum steel gained general acceptance for applications involving creep, and its use and fabrication continued for a number of years without serious difficulties. In 1943, however, at Springdale in the U.S.A., there was a serious failure immediately adjacent to a weld in ½%Mo steel after the sudden closure of a valve. Investigation revealed the presence of graphite dispersed in an intergranular manner in the heat-affected zone of the pipe.[2] Immediate checks on other welded joints showed that many of them were in a somewhat similar condition and that the presence of the precipitated graphite had resulted in a serious loss of ductility in the heat-affected zones. After intensive research it appeared that the graphitization resulted from the decomposition of iron carbide under operating conditions. Steels which had been deoxidized with aluminium showed a marked tendency towards graphitization.[3] There was also some evidence that post-heat treatment had some influence on the suppression of graphitization.[4] British steels did not appear to be susceptible to the trouble and there is no evidence of graphitization occurring in C–Mo weld metal. Fitzgerald and others have shown[5] that the addition of ½%Cr suppressed the tendency towards graphitization and that the creep properties of the modified steel were comparable with those of plain C–Mo steels.

Graphitization, which involves the actual precipitation of graphitic carbon, is frequently confused with another phenomenon known as carbon migration, which has been found to exist in weldments that have been in service at elevated temperatures. This latter occurs most frequently at the low-alloy side of composite welds between ferritic and austenitic materials. A decarburized band is produced in the low-alloy steel as the carbon migrates into the austenitic material. It also appears that carbon migration can occur at an accelerated rate during high-temperature post-heat treatment.[6] Carbon migration has also been reported[7] in 1¼%Cr–½%Mo steel pipe material welded with low-alloy Cr–Mo electrodes. The effect is intensified when using 2¼%Cr–1%Mo electrodes to weld the lower alloy pipe material. Both Rohrig and Blumberg[7] and Christoffel and Curran[8] suggest that carbon migration and decarburization as such have little effect on the physical properties of a composite joint in low-alloy steel and low-alloy weld metal, but this phenomenon is not unnaturally viewed with suspicion.

1–1¼% CHROMIUM–¼% MOLYBDENUM STEELS

The detection and investigation of these disturbing conditions has had repercussions in the welding industry. Welding of the ½%Cr–½%Mo steels fortunately presented little difficulty beyond the exercise of a little extra care in preheating and, in view of the freedom of the weld metal from graphitization, ½%Mo weld metal has generally been used for welding this type of steel. But when the chromium content was raised to 1–1¼% a new difficulty was introduced. Weld metal of a matching analysis for this material is generally considered to be desirable, and the addition of 1–1¼%Cr considerably increased the tensile strength of the weld metal in the as-deposited condition. The commercial electrodes in general use for depositing ½%Mo were usually BS 1719: E317, E110, or E435 types, *i.e.*, electrodes based on rutile, cellulose, or oxide-silicate coatings and all depositing weld metal containing appreciable quantities of hydrogen. The addition of 1% Cr to these electrodes produced weld metal of sufficient tensile strength to be adversely affected by the hydrogen present in the deposit, and fissuring and micro-cracking were prevalent. Unless stringent precautions were taken to preheat the material carefully, and to maintain the preheat during welding and before stress relief, there was also a serious risk of cracking because of the poor as-welded ductility of the alloy weld metal. It was therefore found desirable to use a basic low-hydrogen type of electrode for depositing 1¼%Cr–½%Mo weld metal so as to provide adequate ductility in the as-welded condition and reasonable freedom from micro-cracking. This type of electrode has provided the user with some latitude during fabrication, and a code of practice of interrupted heat-treatment has been drawn up by the American Welding Society[9] based on the use of low-hydrogen electrodes. In their paper on the arc welding of low Cr–Mo steels Bland, Privoznik and Winsor[10] have gone so far as to establish that the static mechanical and impact properties of low-hydrogen deposits made at an interpass temperature of −51°C. (−60°F.) and tested in the as-welded condiiton are equivalent or superior to those of a conventional cellulose–titania electrode deposit made using a 260–316°C. (500–

600°F.) preheat and a post-heat treatment of 1 hr at 677°C. (1250°F.). They do, however, concede that even with low-hydrogen electrodes a preheat of 149°C. (300°F.) might be prudent to avoid cracking on fully restrained joints.

A further metallurgical subtlety has been introduced by the wider use of these electrodes. Whilst the plain ½%Mo electrodes appear to vary little from type to type and brand to brand this is not necessarily true of the 1¼%Cr–½%Mo types. There seems to be quite a significant variation from type to type between electrodes depositing weld metal of nominally similar composition especially in regard to such secondary properties as sensitivity to temper brittleness.[11] There appears to be no published information on whether this variation extends to creep properties.

2¼% CHROMIUM–1% MOLYBDENUM STEELS

To cater for temperature ranges in excess of those practicable with 1¼%Cr–½%Mo steels a great deal of work has been carried out on steels capable of operation at temperatures up to about 577°C. (1070°F.). The most popular choice appears to be the 2¼%Cr–1%Mo steel, but the alternative ½%Mo–¼%V steel also has a wide application. Weld metal of matching composition for both these steels is in a tensile range where basic electrodes are necessary for the provision of weld metal of adequate as-deposited ductility. It is not intended to discuss in this paper the relative merits of these two steels; both are equally weldable and electrodes are available for either material.

The welding of 2¼%Cr–1%Mo steel has received much attention in recent years. It is usual to use an electrode depositing weld metal to match the parent material in analysis, and whilst there is not much published creep data on this deposit it seems to possess adequate creep strength. Gemmil and Murray,[12] on the basis of tests made in 1956, have stated that in short-term tests failure was most liable to occur in the parent plate but that the failure tended to move towards the weld as the duration of the test increased. They considered, however, that the use of a matching composition would give the most likely chance of producing weld metal having creep properties comparable with those of the parent plate.

Much work has been carried out in the U.S.A. on the welding of this type of alloy, but the main emphasis appears to have been placed on the achievement of adequate weld ductility.[13] Since the creep properties of 2¼%Cr–1%Mo steel appear to be dependent to some extent on the heat-treatment cycle[12] it is as well to bear in mind, when considering post-heat treatment procedures, that the weldment is intended for creep resisting applications and to ensure that the treatment specified does not conflict with the conditions necessary for development of the optimum creep resisting properties.

It would appear from published information[14] that if steam temperatures rise appreciably above 566°C. (1050°F.) austenitic steel will be necessary to avoid the use of excessively thick pipe. The recent work on the metallurgy of dissimilar joints between austenitic and ferritic steels has thrown much light on the metallurgical problems encountered in dealing with such joints. For the immediate future, however, it is to be noted that the nuclear power stations employ conventional generating equipment whose temperature and pressure demands are moderate. In the steam generation field welding technology is perhaps in advance of the demands of the designer. This happy state of affairs cannot continue for long and the welding industry will await with interest the problems that will no doubt emerge in the future.

CONCLUSIONS

The progress made in the fabrication, by welding, of installations subject to creep conditions has been a process of gradual evolution and steady improvement rather than a spectacular advance. Creep testing is a slow and costly procedure, but it is a vital means of evaluating the materials and fabrication techniques involved in the construction of steam generating equipment and the like. Unlike general fabrication, the proof of success when welding steels for high-temperature service does not necessarily lie with the production of a sound, crack-free weld. The completed weldment must be able to withstand both high temperature and stress without failure, and long-term testing is the only positive indication of the suitability of the particular welding procedure proposed. It is prudent, therefore, to proceed with caution and to plan well ahead if costly failure is to be avoided. Progress, so far, has been made with due regard for these factors, but there seems to be some lack of data on the effect of welding variables on the service behaviour of some of the more recent materials. If further advances are to be made it will be necessary to extend and amplify the work being done in this field so as to provide a more comprehensive understanding of the problems involved.

ACKNOWLEDGMENTS

The author wishes to record his indebtedness to the Directors of Murex Welding Processes Ltd. for permission to publish this article.

REFERENCES

1. "Report on Elevated Temperature Properties of Chromium–Molybdenum Steels." Special Technical Publication No. 151, American Society for Testing Materials.
2. R. W. EMERSON: "Graphitization of Steel Piping", p. 5, 1944, American Society of Mechanical Engineers.
3. H. WEISBERG: *ibid.*, p. 19.
4. G. V. SMITH and R. F. MILLER: *ibid.*, p. 17.
5. R. C. FITZGERALD, A. V. WILDER, G. V. SMITH, and A. E. WHITE: *Welding J.*, 1948, vol. 27, p. 457*s*.
6. R. W. EMERSON and W. R. HITCHINSON: *Welding J.*, 1952, vol. 31, p. 127*s*.
7. I. A. ROHRIG and H. S. BLUMBERG: *Welding J.*, 1953, vol. 32, p. 815.
8. R. J. CHRISTOFFEL and R. M. CURRAN: *Welding J.*, 1956, vol. 35, p. 457*s*.
9. "Recommended practices for Interruption of Heat Treatment cycles for Low Chromium–Molybdenum Steel Piping Materials." Publication No. D10.3–55T. 1955. American Welding Society.
10. J. BLAND, L. F. PRIVOZNIK, and F. J. WINSOR: *Welding J.*, 1952, vol. 31, p. 783.
11. W. J. LESTER and G. R. PRESCOTT: *Welding J.*, 1955, vol. 34, p. 553*s*.
12. M. G. GEMMIL and J. D. MURRAY: *Iron and Steel*, 1956, vol. 29, p. 150, 173.
13. J. BLAND: *Welding J.*, 1956, vol. 35, p. 181*s*.
14. H. W. KIRKBY: *Metallurgia*, 1955, vol. 51, p. 165.

AUTUMN MEETING, 1958

Some Guidance on Welding Dissimilar Alloy Steels

By M. C. T. Bystram, M.A. (Cantab.)

SYNOPSIS

THE problems of welding various grades of low-alloy ferritic steels, stainless steels, and high-nickel alloys in different combinations are briefly reviewed, taking into account applications at ambient, sub-zero and elevated temperatures.

RECENT trends in the fabrication of industrial plant have led to the increased use of welding for joining materials of different composition. To simplify design and preserve expensive alloys for applications where they are really required, mild and low-alloy steels are joined in different combinations to stainless steels and to high-nickel alloys, and the welding of stainless-clad steels can be considered as a special example of the same trend. In addition, it is sometimes more convenient to use electrodes of composition differing from the base-metal, when matching compositions might lead to metallurgical difficulties.

While many mixed joints have performed successfully for prolonged periods, in some instances specific troubles, such as thermal fatigue or stress corrosion, have limited their applications.

In the present paper a review is made of the factors affecting the welding and performance of such joints.

THE PROBLEM OF THE WEAKEST LINK

Let us assume a metal *A* joined to metal *B* by a multi-pass weld *C*. The complete weldment will be composed of the following elements:

(i) The unaffected metal *A*, with all the characteristics produced by the steel maker
(ii) The heat affected zone of metal *A*, with the junction of metal *A* and weld metal *C*
(iii) The adjacent runs of weld metal *C* most affected by dilution from metal *A*
(iv) The stress carrying runs of weld *C* which are first to bridge the gap
(v) The almost undiluted central ports of weld *C*
(vi) Weld metal *C* adjacent to and diluted by metal *B*; with the junction of weld *C* and metal *B*
(vii) The heat-affected zone of metal *B*
(viii) The unaffected metal *B*.

In specific instances the joint may be further complicated by the insertion of intermediate 'buffer layers' of different composition between the weld and the base metal, the presence of backing strips, and the use of different welding processes in the same weldment.

The mechanical, corrosion, heat- and creep-resisting properties of such a joint are determined by the properties of the weakest element in the service cycle, and this must be borne in mind when designing and evaluating the performance of a joint.

SOURCES OF WEAKNESS IN MIXED WELDS AND THE MEANS OF AVOIDING THEM

Base metal

The choice of base material is usually decided on the basis of the information supplied by the steel manufacturer. It is advisable at this stage to ascertain whether the materials considered have been ever welded in the thicknesses imposed by the design and by the welding processes available.

A comparative study of the composition and metallurgical characteristics of the base metals will usually define the preheat and post-heat treatment required by the more critical alloys. Thus when welding two hardenable steels, the preheat applied should be high enough for the more hardenable grade and the post-heat should be compatible with the performance of both metals.

In exceptional cases when one of the components may be embrittled by preheat, as when welding austenitic 14% Mn steel to a low-alloy hardenable steel, the preheat should be applied selectively and with caution.

Heat-affected zone

The heat-affected zone constitutes a band on both sides of the weld where the base metal shows changes associated with rates of cooling and where temperature-sensitive transformation products may alter locally the properties of the base metal.

The properties of many materials are significantly affected by heat, and the zones adjacent to the weld constitute frequently the weakest link of the weldment.

Martensitic hardening and underbead cracking in low-alloy steels, high-temperature embrittlement (loss of ductility) of plain chromium ferritic steels, precipitation of carbides associated with intergranular corrosion and zones of 'knife-edge' corrosive attack on 18/8 steels, are all phenomena associated with heating

Paper to be presented at the Autumn Meeting in London. Manuscript received 8th August, 1958.
Mr. Bystram is a research metallurgist with Murex Welding Processes Ltd.

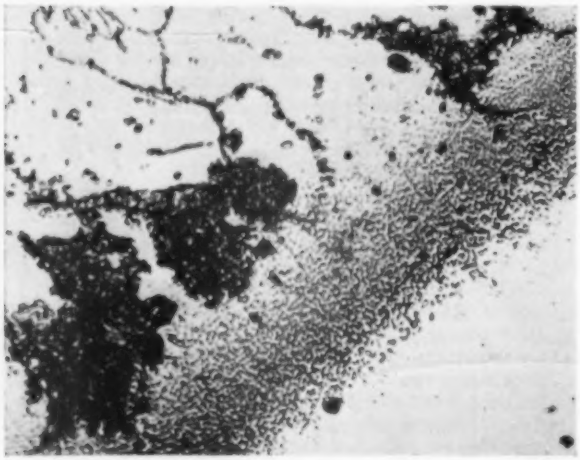
of the adjacent base metal and are likely to occur without regard to the composition of the weld metal.

There are also, however, special affects associated with the relative solubilities of alloying elements, diffusion and differential expansion, which are an inherent feature of mixed weldments.

Thus the high solubility of hydrogen in austenitic welds tends to protect the heat-affected zone from embrittlement by acting as a reservoir for hydrogen.

In a weldment composed of austenitic and ferritic portions the higher solubility of carbon in the austenitic weld metal combined with the presence of carbide formers tends to promote decarburization of the adjacent ferritic material and the formation of clusters of carbides in the welds (Fig. 1).

The difference in the coefficients of expansion of austenitic and ferritic materials may lead to locked-up stresses in the junction area and promote stress corrosion and weakening of the junction by thermal fatigue.



1—Clusters of chromium carbides in Cr–Ni austenitic stainless steel weld, caused by migration of carbon from the adjacent decarburized zone of mild steel (bottom right). Etched in Murakami reagent ×700

Stressed areas of ferritic material may tend to oxidise preferentially in service, thus causing undesirable notches.

Finally, there are occasionally effects of corrosion accelerated by cell action between strongly cathodic and anodic regions.

While such a list of drawbacks may seem at first discouraging the occurrence of all or any one of such effects is usually rare, being mainly limited to high-temperature service, and their occurrence can frequently be alleviated by practically established counter-measures.

In most instances the deficiencies of the heat-affected zone and the problems of the different performance of adjacent materials may be eliminated by a design which completely separates the duties of the component portions. A stainless steel vessel that contains a corrosive medium and which is reinforced mechanically by mild steel attachments on the outside is a classical example of 'separated duties'. There are also numerous examples of applications where the location of a mixed weldment in a safe zone eliminates troubles associated with a variety of operating conditions.

Junction of base-metal and weld metal

If precautions are taken to avoid excessive turbulence in the molten weld pool by avoiding excessive welding speeds, high penetration, and weaving of the electrode, the even and thorough mixing of the deposited weld metal and remelted base material will produce a reasonably homogenous run of weld metal neatly separated from the chemically unaltered base material. Such welds will, for all practical purposes, have as even a distribution of alloying elements as undiluted welds of similar composition, although some degree of heterogeneity exists even in undiluted welds.

2—Local turbulence and mild steel 'whiskers' at junction of austenitic stainless steel weld and mild steel, resulting from excessive weaving ×25

The same applies to the metallurgical structure, *e.g.*, the distribution of such phases as ferrite, austenite and carbides and to a lesser extent to martensitic products which, apart from alteration of composition, are influenced by the heating and cooling and the degree of tempering by the neighbouring runs of weld metal.

Deposition of welds in contact with material of different composition and melting point and associated with a turbulent weld pool leads to anomalies as exemplified in Fig. 2, which shows junction turbulence and mild steel 'whiskers' in a stainless steel weld.

The more controlled downhand deposition in narrow beads, as with buffer layers, tends to eliminate these effects and is frequently an additional precaution worth taking, while on the other hand practices that speed up welding, increase penetration, and oversimplify preparation, can lead to turbulence and frequently do more harm than good, when welding dissimilar metals.

Stress-carrying runs

The first run to bridge the gap of the preparation in a restrained assembly is usually associated with the highest concentration of stresses on the solidifying weld metal, while the poor heat dissipation near the root of the preparation usually leads to higher dilution. In consequence, the root run is more critical as regards cracking when compared with subsequent runs, which suffer less from the effects of dilution and stresses.

To combat these tendencies it is advisable to apply precautions which will tend to:

(*a*) Control dilution effects in the root runs by the choice of electrodes less susceptible to pick-up by virtue of their safer alloy content. In this connection it is also desirable to use weld preparations with an adequate root face and root gap to avoid collapse of the base metal by overheating, and to select the gauge of electrode, the welding current, and the speed of travel that will reduce excessive penetration and turbulence.

(*b*) Reduce abrupt shrinkage strains by frequent tacking and by the application of step-back deposition techniques

(*c*) Avoid the coincidence of maximum strains with maximum dilution by 'buttering' the root of the preparation with a layer of weld metal before deposition of the stress-carrying run. A similar affect may also be obtained by an appropriate choice of backing strip or root insert.

Central undiluted runs of multi-pass welds

Those weld beads which are three runs away from material of different composition, *e.g.*, the third and subsequent layers of a stainless steel weld deposit on mild steel plate, are practically unaffected by dilution and will usually retain about 95% of the alloying elements present in the undiluted state.

This implies in some instances a marked difference in metallurgical structure, *e.g.*, in ferrite content, between the diluted and unaffected central runs, which may lead to lower ductility and cracking in very thick welds.

It is, therefore, sometimes advisable to choose for the central runs in thick welds a more ductile type of electrode, *e.g.*, one of lower ferrite content, which by promoting easy yielding reduces the chances of failure in more brittle areas of the weldment. This applies particularly to thick welds, which may be further embrittled as a result of stress relieving in the medium range of temperatures.

WELDING DISSIMILAR LOW-ALLOY FERRITIC STEELS

Apart from the foregoing general introductory discussion on the possible sources of weakness in mixed welds and the practical means of avoiding them it is appropriate to review in more detail certain groups of mixed welding applications.

The procedure to be adopted for welding dissimilar low-alloy ferritic steels depends on the relative importance of the requirements imposed by the conditions of service.

There are three main groups of applications:

(*a*) Service at ambient temperatures with emphasis on the mechanical properties in tension and with the possible coincidence of fatigue and impact requirements down to, say, —20°C.

(b) Service at subzero temperatures as low as —100°C., with emphasis on impact resistance

(*c*) Service at temperatures up to 550°C., with emphasis on creep performance, resistance to scaling, and freedom from metallurgical defects associated with diffusion processes, phase transformations, and temperature cycling.

Service at ambient temperatures

Constructional plain carbon or low-alloy steels for use at room temperatures can usually be satisfactorily welded with low-hydrogen lime-fluorspar electrodes having a weld metal strength of 35–45 tons/sq.in. with the application of an appropriate preheat up to 300°C.

Where there is fatigue and shock, or in those instances where the presence of tough welds with high ductility or crack resistance is desirable, austenitic Cr–Ni electrodes of BS 2926 Class *E* or *F* can be used with great success, as exemplified by applications in the armament and motor industries.

While stress relieving at 650°C. is often necessary after welding with low-hydrogen low-alloy electrodes, this is seldom so with Cr–Ni austenitic electrodes for which stress relief is recommended mainly for sections above $\frac{3}{4}$ in. thick.

Service at sub-zero temperatures

The $3\frac{1}{2}$%Ni steels are often chosen for service at sub-zero temperatures and, whereas welding them with $3\frac{1}{2}$%Ni electrodes of the low-hydrogen type with a preheat of 100°C. and post-heat at 650°C., will generally secure impact resistance of over 15 ft/lb (Charpy Keyhole 10 mm.sq) at —100°C., attachment of this steel to lower impact grades of *C* steel can be usually effected with low-hydrogen lime-fluorspar electrodes of the mild steel type to obtain 20 ft.lb at —50°C.

For lower temperatures, *e.g.*, —120°C., the use of austenitic Cr–Ni electrodes of BS 2926 Class *E* or electrodes of the Inconel (75Ni/15Cr/5Fe) type is preferable. For Class *E* welds stress-relieving is undesirable because of a tendency for decarburization of the heat-affected zone and embrittlement of the ferritic-austenitic junction associated with unusually rapid carbon migration in the heat-affected zone of these steels during the post-heat treatment at 650°C.

Service at temperature up to 550°C.

For service at temperatures from 350–550°C. for steam piping and in the petroleum industry the materials are more standardized, and the most frequent 'mixed welding' applications are adequately covered in Table I, which shows the composition variants of Mo and Cr–Mo steels, appropriate low-alloy (Class *A*, *B*, *C*, *D*) ferritic electrodes to BS 2493:58, and the associated heat treatments.

The following guidance is pertinent:

(1) When two compositions of different hardenability are to be welded the higher preheat and post-heat should be chosen corresponding to the more hardenable steel and should be applied to both tacking and welding operations.

(2) As a certain amount of Cr is beneficial for overcoming graphitization tendencies in service, the too frequent use of the plain $\frac{1}{2}$% Mo composition *A* should be avoided.

(3) The electrodes of compositions corresponding to the more hardenable steel will require more meticulous attention to preheat to avoid martensitic cracking and to ensure the required weld ductility. A weldment that does not contain a member with an alloy content higher than 1% Cr–$\frac{1}{2}$% Mo, does not require the maintenance of preheat temperatures on interruption of welding, and can be stress relieved at any convenient time, whereas a more highly alloyed weldment requires the

Table I

Welding of dissimilar Mo and and Cr–Mo low-alloy steels with ferritic low-alloy electrodes

Types of Steel	*Preheat, °C.*	*Stress Relief, °C.*	*Mild Steel*	*½ Mo*	*1Cr–½Mo*	*2¼Cr-1Mo*	*5Cr–½Mo*
			—	100–150	150–200	200–250	200–250
			600	650	650	690	720
½Mo	100–150	650	Mild Steel Class 6 or Type *A*	Type *A*			
1Cr–½Mo	150–200	650	Mild Steel Class 6 or Type *B*	Type *B*	Type *B*		
2¼Cr–1Mo	200–250	690	Mild Steel Class 6 or Type *B*	Type *B*	Type *B*	Type *C*	
5Cr–½Mo	200–250	720	Type *B*	Type *B*	Type *B*	Type *C*	Type *D*

BS 2493:1958
- Mild Steel Class 6 electrode – unalloyed basic low-hydrogen type
- Class *A* – ½Mo basic low-hydrogen type
- Class *B* – 1Cr–½Mo basic low-hydrogen type
- Class *C* – 2¼Cr–1Mo basic low-hydrogen type
- Class *D* – 5Cr–½Mo basic low-hydrogen type

maintenance of preheat until it is either partially stress relieved for ½ hr at 600°C., or finally stress relieved at the appropriate temperature.

This justifies the preference for the *B* composition and avoidance of *C* and *D* types in Table I.

(4) The limited tendency for carbon migration between the steels in question is caused mainly by the difference in carbide-forming elements on both sides of the junctions, hence the use of electrodes of intermediate composition *B* when welding extreme members of this series.

Whilst, in principle, it is preferable to weld the steels in Table I with ferritic low-hydrogen electrodes matching either one of the base materials, or with electrodes of intermediate alloy content, welding with austenitic Cr–Ni electrodes to BS 2926 Class *H*, *E*, and *F* has sometimes been also successful, in particular when adequate control of preheat and post-heat is difficult.

Geerlings and Kerkoff[1] have shown both theoretically and practically (by over 30 years of successful service) that 5%Cr–½%Mo pipes welded with austenitic Cr–Ni electrodes do not show serious deterioration from differences of coefficients of expansion (thermal fatigue), carbon migration and other complications provided that the maximum service temperature and the wall thickness of the pipes are limited to a definite value for every pipe diameter.

WELDING MILD AND LOW-ALLOY STEELS TO VARIOUS GRADES OF STAINLESS STEELS

The choice of electrodes for welding together ferritic and austenitic steels is not easy, since it requires a detailed evaluation of the conditions of service and frequently necessitates an intelligent compromise.

The usefulness of Schaeffler's constitutional diagram for stainless welds, with his graphical extrapolation techniques to predict the effects of dilution and to facilitate a choice of appropriate electrodes, has been already discussed in other publications,[2, 3] (*see* Fig. 3).

In this paper attention will be confined to a concise review of current practice in this domain as summarized in Table II, which shows the various types of electrodes employed for different combinations of the four main groups of steel under consideration.

The BS 2926 electrodes Class *E* (20Cr/9Ni/3Mo) and Class *F* (25Cr/12Ni) are most generally suitable for mixed welding applications. They have the advantage of high total alloy content, which prevents excessive dilution leading to martensitic cracking, while at the same time preserving residual amounts of ferrite, which counteract the tendencies for hot cracking even under conditions of severe restraint.

The use of Class *H* (25Cr/20Ni) electrodes, whilst justified on the basis of their total alloy content, tends to be dangerous under conditions of severe restraint, owing to the hot cracking tendencies of fully austenitic welds. Their use for welding plain chromium stainless steels of both the martensitic and ferritic types is less dangerous, since the weld metal may acquire a residual ferrite content as a result of dilution.

For service above 500°C. further refinements of ferrite control may be needed. The effects of differential expansion and carbon migration may be alleviated to some extent by the use of special prefabricated transition pieces, to which on one side ferritic and on the other austenitic material may be welded with electrodes of similar constitution.

Recently, high Ni–Cr alloy electrodes, which deposit weld metal having a coefficient of expansion intermediate between that of austenitic and ferritic material, have been advocated for use in critical conditions of thermal fatigue and carbon migration.[4] If the hot-cracking resistance of this type of electrode could be consistently improved they would no doubt prove useful for many critical mixed welding problems.

JOINING OF HIGH NICKEL BASE ALLOYS TO OTHER MATERIALS

From the metallurgical standpoint most nickel-base alloys can be considered as a high-nickel modification of fully austenitic stainless steels. But it is not advisable to deposit stainless steel weld metal in contact with high-nickel alloy material in general and the copper-bearing grades in particular. The pick up of both nickel and copper tends to lead to hot cracking, and frequently the welds do not meet the service requirements.

The welding of the high-nickel creep-resisting alloys with precipitation hardening tendencies presents its own additional difficulties. The metal-arc welding processes give welds with lower creep performance than the wrought parent material, owing partly to lack of efficient recovery of aluminium and titanium and partly to the cast character of the weld metal. On the other hand, increased recovery of aluminium and titanium in the weld metal sometimes leads to loss of ductility and cracking, whilst the unbalancing of the deoxidation reactions may cause porosity near the junction zone.

Table II

Choice of electrodes for welding mild, low-alloy, and different grades of stainless steels in different combinations

Material			*Mild or Low-Alloy Steel*	*Martensitic Stainless Steel 12%Cr or 18Cr/Ni*	*Ferritic Stainless Steels 17Cr, 20Cr, 27Cr*	*Austenitic Stainless Steels containing Cr–Ni and Minor Alloying Elements*
	Preheat °C.	Post-heat °C.	Up to 250 Up to 700	Up to 350 750	200°C —	— —
Mild or low-alloy steels	250	700	(1) Ferritic low hydrogen electrodes as in Table I and Table II (2) Austenitic *E, F, G*			
Martensitic stainless steels. 12Cr; 18Cr/2Ni	350	750	(1) Austenitic *E, F, G* (2) Low-hydrogen mild steel	(1) Austenitic *E, F, G* (2) 12 Cr		
Ferritic stainless steels. 17%Cr; 20%Cr; 27%Cr	200	—	(1) Austenitic *G, F, G** (2) 20%Cr	(1) Austenitic *G** (2) 20%Cr	(1) Austenitic *G** (2) 20%Cr and 27%Cr	
Austenitic Cr–Ni stainless steels with minor alloying elements	—	—	(1) Austenitic *E, F, G**	(1) Austenitic *E, F, G**	(1) Austenitic *G**	Austenitic electrode preferably with residual ferrite and better in corrosion resistance than the steels.

* Austenitic Cr–Ni stainless steel electrodes to BS 2926:1957 } Class *E* – 20Cr–9Ni–3½Mo; Class *F* – 25Cr–12Ni; Class *G* – 25Cr–20Ni

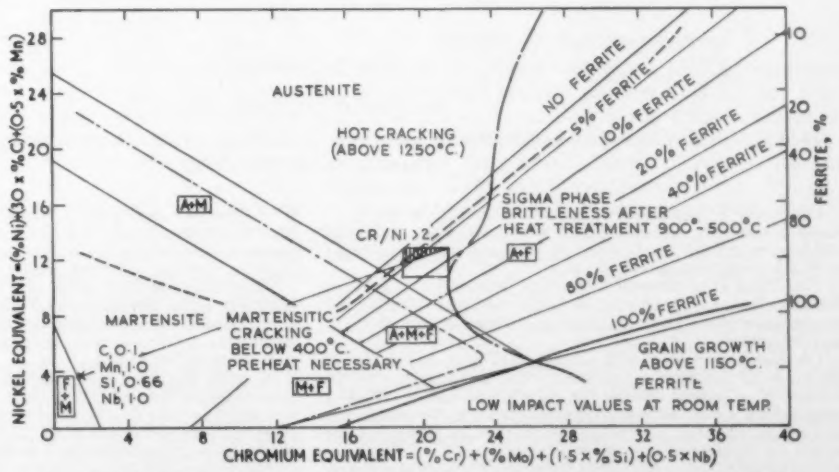
In general therefore Class I welds in the high-nickel alloy type of material can be obtained only with close attention to details of execution. Cleanliness of weld preparation (removal of patina), use of starting tacks (to avoid 'start' porosity), slight preheat (100°C.) when welding thicker sections, redrying of electrodes, chipping out of defects, and all precautions that will give easier control of the welding operations must be applied if best results are to be secured. The use of small-gauge electrodes on d.c. supply, with the lowest convenient current, is also frequently an advantage since overheating the weld can also lead to porosity, especially with the Mo-bearing nickel alloys.

The recommended electrodes for welding nickel-base to iron-base alloys are shown in Table III. The 80Ni/17Cr/Nb, 60Ni/33Cu/3Nb, 65Ni/18Mo/13Cr/5W and pure nickel electrodes cover most of the combinations successfully, and the choice of electrode will frequently depend on the details of the service requirements and the applicability factors such as position of welding, degree of restraint etc.

The 60Ni/33Cu/3Nb electrode should not be confused with the niobium free variety of Monel, which is incompatible with ferrous materials and whose use results in weld cracking.

Superimposed rectangle corresponds with weld metal of the following analysis:

T.C.	0·1%
Si	0·66%
Mn	1·0%
Nb	1·0%
Cr	17·5–20%
Ni	8–10%



3—Schaeffler's diagram for stainless steel weld metal, showing approximate regions of defects

Table III

Welding of nickel-base to iron-base alloys

Alloys	*All stainless and low-alloy steels.* (For the hardenable steels preheat as in Table I)	*Nickel chromium Alloys with Iron less than 50% and Al, Ti and Mo residual*	*Nickel Copper Alloys* (e.g., 63Ni–35Cu)	*Nickel Molybdenum Alloys with or without Fe, Cr, W additions*
All stainless and low-alloy steels. (For hardenable steels preheat as in Table I.)	As in Table I	80Ni–17Cr–Nb 60Ni–20Cr–Nb 65Ni–18Mo–15Cr–3W	60Ni–33Cu–3Nb Pure Nickel 80Ni–17Cr–Nb	80Ni–17Cr–Nb 65Ni–18Mo–15Cr–3W
Ni–Cr alloys with iron less than 50% with or without Al, Ti, Mo.		80Ni–17Cr–Nb 60Ni–20Cr–Nb	80Ni–17Cr–Nb 60Ni–33Cu–3Nb	80Ni–17Cr–Nb 65Ni–18Mo–15Cr–5W
Nickel copper alloys			63Ni–33Cu 63Ni–33Cu–3Nb	65Ni–18Mo–15Cr–5W 60Ni–33Cu–3Nb
Nickel molybdenum alloys with or without Fe, Cr, W				Appropriate Matching Electrodes, *e.g.*, 68Ni–25Mo 65Ni–18Mo–15Cr–3W

Attention should be paid also to such details of analysis as the silicon content of the nickel alloys. Although it is desirable for some heat-resisting application, silicon considerably increases the chances of hot-cracking in welds in such alloys as a result of dilution pick-up.

The 80Ni/17Cr/Nb type of electrode is probably the one most suitable for general use, and can even be applied for joining cast iron and copper to any member of the four groups of alloys listed in Table III.

The 65Ni/18Mo/15Cr/3W electrode is frequently used when a higher degree of hot-crack resistance is required.

CONCLUSION

The subject of mixed welding is difficult to present in a single article, and the more complicated applications require a detailed consideration of the factors involved.

Some of the problems involved and some generally applied solutions given in the paper may, however, provide useful guidance.

Many problems of joining dissimilar metals have still no satisfactory solution although it is hoped that, with reservations, the review of current practice listed in the Tables will provide the answer for the more simple applications.

ACKNOWLEDGMENTS

The author wishes to record his indebtedness to the Directors of Murex Welding Processes Ltd. for permission to publish this paper and to Dr. W. I. Pumphrey and Mr. J. F. Mercer for their help and constructive criticism during its preparation.

REFERENCES

1. H. G. Geerlings and W. P. Kerkhof: *Brit. Welding J.*, 1956, vol. 3, p. 475.
2. A. L. Schaeffler: *Iron Age*, 1948, vol. 162, p. 72.
3. M. C. T. Bystram: *Brit. Welding J.*, 1956, vol. 3, p. 42.
4. J. T. Tucker and I. Eberle: *Welding J.*, 1956, vol. 35, p. 529s.

BOOK NOTICE

WELDING DISTORTION

The Calculations of Deformations of Welded Structures by N. O. Okerblom. (Translation from the Russian): H.M.S.O., 1958. Price 15s. net. (234 pp., illus.)

This book is a translation, prepared for D.S.I.R. by L. C. Ronson and T. A. Churchman, of a book originally published in Moscow in 1955, and is based on work carried out in Russia over a considerable period of years.

The object is to produce a practical method for calculating the distortions to be expected in welded structures so that they can be allowed for, or minimized by a suitable choice of design and procedures.

The book commences with a lucid qualitative description of the types of distortions that occur, their significance, and an outline of a general scheme for their determination. This is followed by an exposition of the basic theory for calculating distortions, starting from the theoretical work of Rosenthal and others on the temperature distributions around a moving point source of heat. From this temperature distribution, the distortions are derived by well established principles and a minimum of acceptable assumptions regarding the properties of the material in the elastic and plastic ranges. The theory is fully developed, and simplified into a form which can be applied to actual structures, with numerically worked examples.

Very little evidence is given as to the agreement of the calculated and actual deformations, though it is stated (p. 192) that a comparison of the results with actual measurement shows reasonably good agreement, both in the nature and the magnitude of the deformations.

Probably the most interesting part of the book is in the final two chapters, which discuss methods for reducing welding deformations, and the choice of assembly sequences. These give practical guidance which is readily applicable. Although based on the theory, only elementary mathematics are used.

The book will be found helpful by all who are interested in the subject.

G. M. Boyd

Welding

RESEARCH

Weldability of 3½% Ni–Cr–Mo Steel

By C. L. M. Cottrell, Ph.D., M.Sc., A.I.M., A.M.Inst.W., and K. Winterton, Ph.D., B.Sc., A.I.M.

SYNOPSIS

THE transformation characteristics and the mechanical properties of a commercial 3½% nickel-chromium-molybdenum steel were studied by simulating, as far as possible, the conditions occurring in the heat-affected zone adjacent to metal-arc welds.

Continuous-cooling transformation diagrams were produced for the steel after heating to different peak temperatures and cooling at different rates. Low levels of residual hydrogen in high-tensile steels welded without preheat probably have an adverse effect on resistance to hard-zone cracking. The dead-load tensile test on simulated weld heat-affected zones has again given a direct indication of the behaviour of the steel during welding.

IN earlier work[1, 2] it was shown, by means of rapid dilatation tests, that the tendency of alloy steels to cold cracking in the heat-affected zone during metal-arc welding was related to the temperature for completion of austenite transformation during cooling at the given welding rate. This temperature was found to depend upon the type of welding electrode used and was lowest for electrodes giving welds of low diffusible hydrogen content. Critical end-of-transformation temperatures of 290° and 245°C. were established for rutile-coated ferritic and low-hydrogen ferritic electrodes, BS 1719 classes 2-- and 6-- respectively. It was also shown[3] that if there was a critical temperature for rutile-coated austenitic electrodes it was below about 205°C.

Parallel investigations[4, 5] showed that cold cracking could be simulated in a dead-load tensile test piece. A delayed brittle fracture was produced at low stress levels when conditions (hydrogen content and cooling rate) which produced cracks in practice were imitated in the test piece, immediately before application of the dead load.

This report describes a continuation of the work using a high-alloy steel conforming to BS 970 En 28.

Report FM.8/106 of the British Welding Research Association. The authors were members of the research staff of the Association when this report was prepared.

MATERIALS

The steel was supplied in the form of 0·8 in. and 1 in. thick plate in the hardened and tempered condition. The analysis and mechanical properties of the steel are given in Table I.

Table I

Analysis and mechanical properties of En 28 steel

C, %	*Mn*, %	*Si*, %	*S*, %	*P*, %	*Ni*, %	*Cr*, %	*Mo*, %	*V*, %	*H* (*ml/100gm*)
0·31	0·47	0·31	0·010	0·019	3·40	0·82	0·56	0·11	0·35

Proof Stress tons/sq.in. 0·02%	0·3%	0·5%	*U.T.S., tons/sq.in.*	*Elong. on 4√A, %*	*Red. in area, %*	*Hardness D.P.N.*
62·4	64·7	65·4	70·2	19	50	385

The metal-arc welding electrodes used were of the austenitic 18/8 type. The bare ferritic welding wire was of the Si–Mn type.

EXPERIMENTAL PROCEDURE

Controlled thermal severity[6] (C.T.S.) cracking tests of thermal severity number (T.S.N) 10½ were made on the steel using 10, 8 and 4 s.w.g. austenitic electrodes. C.T.S. tests of severity T.S.N. 12 were made using the self-adjusting-arc process (argon shield) with $\frac{3}{32}$ in. dia. ferritic wire.

The rapid dilatation tests were made on ½ in. long tubular specimens using the technique described in an earlier report.[1] Specimens were heated to peak temperatures of either 1240° or 1330°C., and were cooled at six different rates.

Slow tensile and dead-load tensile tests were made on notched specimens of the steel after they had been heated to a peak temperature of about 1300°C., and cooled at three rates (*see* Table III) as described earlier.[4, 5] Some specimens were heat-treated, after they had been degassed by vacuum heating up to 950°C. (*i.e.*, they contained 0·35 ml/100 gm less hydrogen than the standard specimens).

Table II

Welding test results

Electrode	*Test severity (T.S.N.)*	*Total arc energy kJ/in.*	*Cooling rate at 300°C. °C/sec*	*Approx. cooling time (870°–300°C.) sec*	*Hard-zone cracking (% vertical leg length)*
Austenitic 10 s.w.g.	10½	21·4	40	4·5	37
„ 8 s.w.g.	10½	31·6	25	7	15
„ 4 s.w.g.	10½	57·0	9	20	21
Ferritic $\frac{3}{32}$ in.	12	39	22	8	100* approx.

* Duplicate tests on a 2½% Ni–Cr–Mo steel of higher carbon content.
All tests were made on plates at room temperature (15–20°C.).

TEST RESULTS

Weldability

The results of the weldability tests are given in Table II. The welds were made on plates at room temperature and all showed evidence of cold cracking in the heat-affected zone. It should not be inferred from these results that the steel is unweldable, since it has been shown[7] that a similar steel can be welded satisfactorily if the cooling rate is reduced by preheating.

Transformation characteristics of simulated heat-affected zones

The progress of transformation of austenite with respect to temperature and time was estimated from the dilatation/temperature and time/temperature curves in a similar manner to that described in an earlier report. Continuous cooling transformation diagrams for the steel cooled from peak temperatures of 1240° and 1330°C. are shown in Figs. 1 and 2 respectively.

With all cooling rates the transformation was fully martensitic. The structure obtained using a cooling time of 14 secs (870–300°C.) and a peak temperature of about 1330°C. is shown in Fig. 3.

Hardness explorations were made on transverse sections of the dilatation specimens, using a diamond pyramid indenter and a 10 Kg load. The results are shown in Fig. 4 for the two peak temperatures and some points are included from weld heat-affected zones for comparison. The results show that the hardness obtained is reduced by increasing the peak temperature from 1240° to 1330°C. Two tests were also made on degassed steel, and there was little effect on progress of transformation.

Mechanical properties of simulated heat-affected zones

The effect of cooling rate and residual hydrogen content on the strength of the steel was also studied. The results of slow tensile tests made on the as-received steel after simulating the welding thermal cycles are shown in Table III.

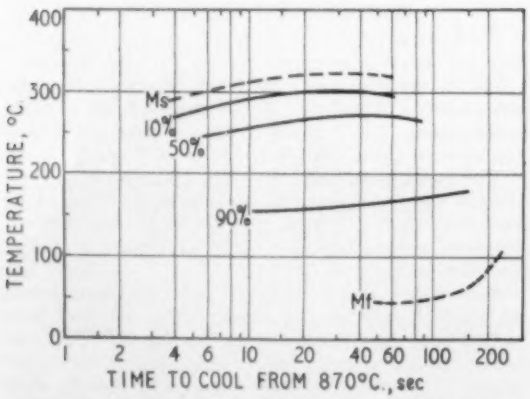
Table III

Slow tensile test results

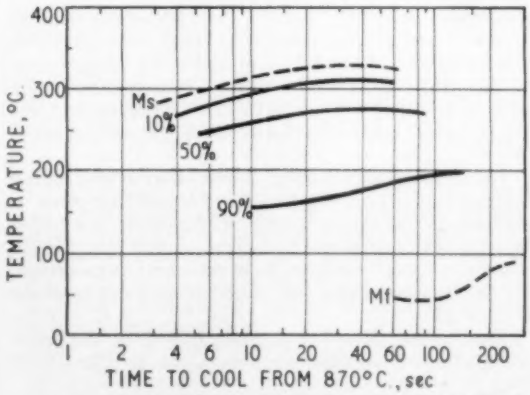
Cooling rate	*Cooling time (870°–300°C.) sec*	*U.T.S., tons/sq.in.*
A	4·3	95·0
C	14	128
E	48	120
As-received material		86·5

With all cooling rates used the material was stronger than that in the as-received (hardened and tempered) condition.

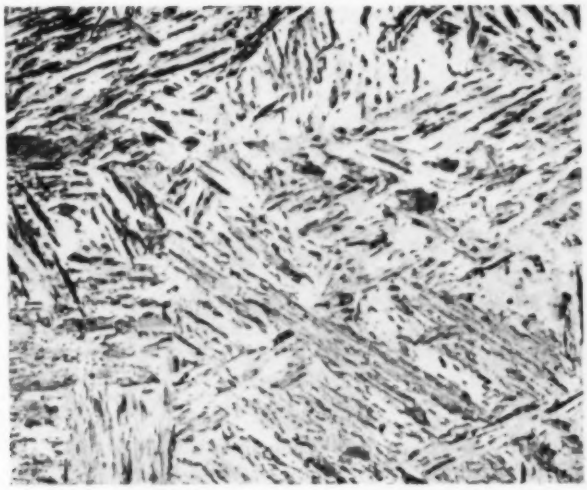
The results of dead-load tensile tests on as-received and degassed steel, after simulating the welding



1—Continuous-cooling transformation diagram for 3½% Ni–Cr–Mo steel, quenched in argon. Austenitising temperature 1240°C.



2—Continuous-cooling transformation diagram for 3½% Ni–Cr–Mo steel, quenched in argon. Austenitising temperature 1330°C.



3—Structure in 3½% Ni–Cr–Mo steel. Cooling time 14 sec (870–300 C.). Etched 2% nital ×1000

thermal cycle, are shown in Fig. 5.* The as-received material showed a marked drop in strength after heat-treatment, and the degassed material, which contained 0·35 ml/100 gm less of hydrogen, also showed a drop in strength; this was not so marked at the lower cooling rates.

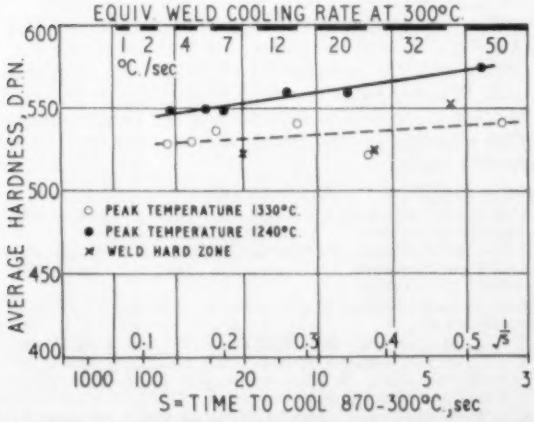
DISCUSSION

The results of the rapid dilatation tests can be compared with the weldability test results. In earlier work it was found that no cold cracks were observed in the heat-affected zone of austenitic welds when the end-of-transformation temperature was above about 200°C.[3,5] The end-of-transformation temperature of the 3½% Ni–Cr–Mo steel is plotted against cooling time in Fig. 6. Since considerable cracking was observed in welding with a cooling time (870°–300°C.) of about 20 sec, the end-of-transformation temperature must be considerably higher than 70°C. to give crack-free heat-affected zones when welding with austenitic electrodes (almost zero diffusible hydrogen). Therefore the critical end-of-transformation temperature for steels welded with austenitic electrodes is likely to be between 70° and 200°C., and the same range of temperature may also apply for steels welded with bare ferritic wire (argon shielded).

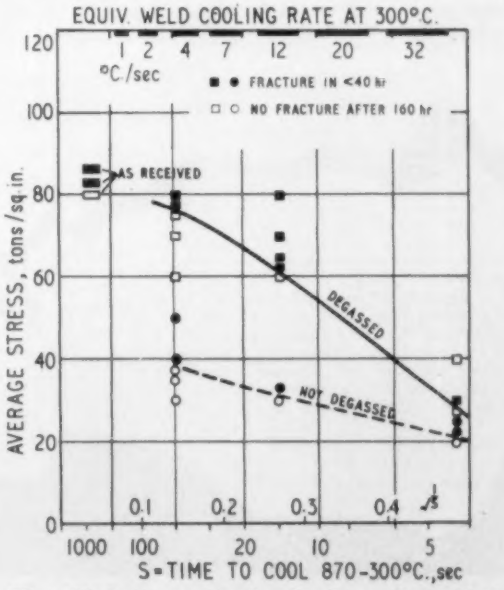
The results of the dilatation tests have suggested that, for the 3½% Ni–Cr–Mo steel, the temperature (M_s) at which martensite begins to form may be affected by the rate of cooling, as shown in Figs. 1 and 2. This suggestion is of interest in view of the widely held belief that M_s temperature is independent of cooling rate. The M_s temperature appears to vary from about 285°C. to about 325°C. The calculated M_s temperature for the steel according to Nehrenberg[8] is about 305°C., which lies in the middle of the observed range. It would be of interest to determine whether this apparent variation of M_s temperature with cooling rate applies for other steels or whether it is within the experimental error of this method of analysis, which may be larger at high cooling rates.

The mechanical tests on simulated weld heat-affected zones have shown that the residual hydrogen in the steel (0·35 ml/100 gm) is sufficient to lower the dead-load rupture strength of the steel to below 40 tons/sq.in. after imitating the welding thermal cycle. Figure 7 illustrates the extreme embrittlement that occurs, a grain having been partially torn away in the neighbourhood of the fracture. In addition, Fig. 8 shows a very fine brittle crack emanating from the root of one of the threads. This result agrees with the observation of cold cracking in the heat-affected zone when the steel is welded with coated austenitic electrodes or bare ferritic wire (argon-shielded), since

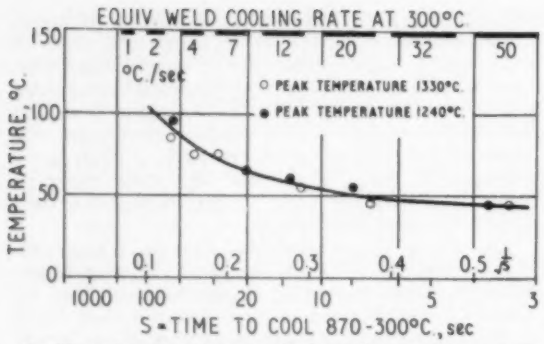
* The points on the extreme left of the diagram ($S = 1000$) are for as-received (hardened and tempered) material with no subsequent treatment.



4—Effect of peak temperature and cooling time on hardness of 3½% Ni–Cr–Mo steel



5—Effect of hydrogen content and cooling time on the dead-load rupture stress of a 3½% Ni–Cr–Mo steel



6—Effect of cooling time on end-of-transformation temperature of a 3½% Ni–Cr–Mo steel during continuous cooling

both these weld metals have almost zero diffusible hydrogen and cannot therefore be responsible for the extra hydrogen in the heat-affected zone.

The tests on the degassed steel are of considerable interest, because with the lower cooling rates the dead-load rupture stress of the material was almost doubled (*see* Fig. 5). This result shows the very definite effect of small amounts of residual hydrogen on the dead-load rupture stress and hence on the weldability of the steel.

It is considered that the degassing treatment did not remove all of the residual hydrogen in the steel and that the small amount remaining caused the dead-load rupture stress of the thermally treated degassed material to be lower than that of the as-received material (82 tons/sq.in.). This has been checked by removing as far as possible all sources of extraneous hydrogen during the thermal cycle in tests on the degassed material. This involved drying the nitrogen gas atmosphere and testing the specimen immediately after degassing, *i.e.*, before there was time for the formation of an appreciable surface film of water on the specimen. A specimen was also heated in an argon atmosphere to observe whether the nitrogen atmosphere had any effect. In all these tests there was no significant improvement in rupture stress over that of the degassed specimen heated in undried nitrogen.

7—Embrittlement after thermal treatment; grain partially torn away. Unetched ×500

8—Embrittlement after thermal treatment; fine crack from thread root. Unetched ×500

The only way in which it could be proved definitely with this steel that a small quantity of hydrogen, remaining after the degassing treatment, was responsible for the drop in rupture stress would be to vacuum melt the steel and to machine a specimen out of the solidified melt. This is undesirable since other elements would be lost in the vacuum melting treatment. A better method would be to investigate the effect on a less highly alloyed steel, where the removal of hydrogen by the normal vacuum heating technique would probably be sufficient to give high rupture strength properties after simulating the welding thermal cycle. A suitable material is the 2¼% Ni–Cr–Mo steel En 25.

CONCLUSIONS

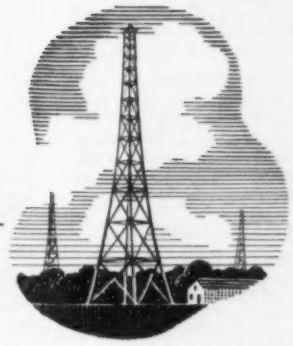
Continuous cooling transformation diagrams covering normal weld cooling rates have been produced for a 3½% Ni–Cr–Mo steel conforming to BS 970 En 28. The results suggest that a small amount of residual hydrogen (0·35 ml/100 gm) in a high-tensile steel is likely to have an adverse effect on its hard-zone crack resistance when the steel is welded without preheat.

The dead-load rupture stress of the steel is lowered considerably after simulating the heat treatment that occurs adjacent to welds on plate at room temperature. This is in agreement with the liability of the steel to crack when welded without preheat. Degassing the steel (removal of hydrogen) improves the dead-load rupture stress.

REFERENCES

1. C. L. M. Cottrell: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 17–24.
2. C. L. M. Cottrell: *Brit. Welding J.*, 1954, vol. 1, pp. 409–412.
3. C. L. M. Cottrell: *J. Iron Steel Inst.*, 1954, vol. 176, pp.273–282.
4. C. L. M. Cottrell: *Brit. Welding J.*, 1954, vol. 1, pp. 177–186.
5. C. L. M. Cottrell: *Brit. Welding J.*, 1955, vol. 2, pp. 75–80.
6. C. L. M. Cottrell: *Welding J.*, 1953, vol. 32, pp. 257*s*–272*s*.
7. A. H. Cottrell, K. Winterton and P. D. Crowther: *Trans. Inst. Welding*, 1941, vol. 4, pp. 17–21.
8. A. E. Nehrenberg: Contribution to discussion on paper by Grange and Stewart, *Trans. A.I.M.M.E.*, 1946, vol. 167, pp. 494–498.

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

Autumn Meeting 1958

The following is the programme of the Autumn Meeting of the Institute for 1958:

Wednesday, 5th November

7.15 for 7.45 p.m.—Annual Dinner at the Park Lane Hotel.
Tickets inclusive of cocktails £3. Members are entitled to one ticket at £2 10*s.* on personal application.

Thursday, 6th November

10.0 a.m. to 12.30 p.m.—Presidential Address by Mr. J. Strong, M.A., followed by the presentation and discussion of the following papers:
"*Current and Pressure Wave Shapes used in Resistance Welding*", by W. A. Knipe (Aug.)
"*Development of the Tungsten-Arc Cutting Process*" by R. A. Cresswell (Aug.)
"*Application of the Numerical Analogue System to Oyxgen Cutting Machines*" by L. J. Hancock and J. R. Arrowsmith (Aug.)
"*Developments in the Inert-Gas Tungsten-Arc Fusion Spotwelding Process*" by F. W. Copleston and L. M. Gourd (Sept.)
"*Developments in Power Sources for Inert-Gas Tungsten-Arc Welding*" by M. Waller (Sept.)
"*New Developments in Arc Welding Processes and Their Applications*" by P. Shaw and D. B. Tait (Oct.)

2.0 to 4.0 p.m.—Presentation and discussion of the following papers:
"*Why Weld Automatically?*" by I. C. Fitch (July)
"*Flame Cutting and Jigging for a Nuclear Power Station*" by J. W. Gethin (Sept.)
"*Carbon Dioxide Welding and Production of Automobile Chassis Side Members*" by S. Astley (Sept.)
"*Positioners for Automatic Welding of Atomic Reactor Housings*" by W. A. Davis (Oct.)

4.0 p.m. Tea break

4.30 p.m.—Coaches leave Institute for visits to works of:
British Aluminium Co. Ltd., Chalfont Park, Gerrards Cross
British Oxygen Gases Ltd., Cricklewood
Hancock & Co. (Engineers) Ltd., Croydon
Murex Welding Processes Ltd., Waltham Cross
Sciaky Electric Welding Machines Ltd., Slough

8.0 p.m.—Coaches return to London.

Friday, 7th November

10.0 a.m. to 12.30 p.m.—Presentation and discussion of the following papers:
"*Some Aspects of Cross Wire Welding of Aluminium Alloys*" by G. H. Batten (Sept.)
"*Metal Arc Welding of Aluminium Bronze Alloys*" by M. K. Williams and W. I. Pumphrey (Oct.)
"*Experiments with Self-Guiding Equipment for Aluminium*" by J. E. Tomlinson and R. V. Blewett (Oct.)
"*High-Current Inert-Gas Metal-Arc Welding of Aluminium*" by A. A. Smith and P. T. Houldcroft (Sept.)
"*Welding of Some Creep Resisting Steels*" by J. F. Mercer (Oct.)
"*Some Guidance on Welding Dissimilar Alloy Steels*" by M. C. T. Bystram (Oct.)
"*Manual 'Open Air' Welding of Reactive Metals*" by J. C. Borland and W. G. Hull (Sept.)

All the papers for the technical sessions have been published in the July–October issues of the BRITISH WELDING JOURNAL, as indicated in parentheses.

The Principal Guests at the Dinner will be the Rt. Hon. Aubrey Jones, P.C., M.P., the Minister of Supply; the Rt. Hon. Lord Coleraine, P.C.; and the Rt. Revd. The Bishop of Kensington.

Application forms for the Meeting are being circulated to members.

Symposium on Aluminium Pressure Vessels

As already announced, a Symposium arranged jointly with the Institution of Mechanical Engineers, the Aluminium Development Association, and the Institution of Chemical Engineers will be held on **28th October** at the offices of the Institution of Mechanical Engineers.

The intended programme is as follows:

1st Session—2.0–4.0 p.m.

"*Critical Review of Existing Codes of Practice for the Construction of Pressure Vessels in Aluminium and its Alloys*", by R. J. Rose and J. G. Young (British Welding Research Association).
"*Basic Properties of Aluminium Alloys used in Pressure Vessels*", by E. Elliott (Aluminium Development Association).

Break for tea—4.0–4.30 p.m.

2nd Session—4.30–6.30 p.m.

"*Fabrication of Aluminium Pressure Vessels*", by J. F. Lancaster (Kellogg International Corporation).
"*Experience with Aluminium Pressure Vessels*", by C. A. Terry and G. B. Roberts (Imperial Chemical Industries Ltd.).

The Chair at the 1st session will be taken by Professor Hugh Ford (Imperial College of Science and Technology), and at the 2nd session by Dr. E. G. West (Technical Director of the Aluminium Development Association).

There will be a combined charge of 10*s.* for papers and registration, and tea will cost 1*s.* 6*d.* Registration forms and further particulars may be obtained from the Secretary of the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S.W.1.

Spring Meeting 1959

The Spring Meeting of the Institute next year will be held in London, and is being organized in co-operation with the Committees of the North and South London Branches. It will partly coincide with the Engineering, Marine, Welding, and Nuclear Energy Exhibition at Olympia, so that members visiting the exhibition will have the opportunity to take part in some or all of the engagements of the Meeting.

The tentative programme provides for a Reception at the Institute on the evening of **Monday, 20th April**; works' visits on **Tuesday** and **Thursday, 21st** and **23rd April**; and morning technical discussion meetings at the Institute on **Wednesday** and **Friday, 22nd** and **24th.**

On the Wednesday evening members will be able to attend the Joint Dinner of the London Branches at the Connaught Rooms.

Second Annual Lecture

Sir Leonard Owen, C.B.E., M.I.C.E., M.I.Mech.E., M.I.Chem.E., Managing Director of the U.K. Atomic Energy Authority, has accepted the President's invitation to deliver the Second Annual Lecture at the Institute on Thursday, 12th

March, 1959, at 6.30 p.m. His subject will be 'Welding and the Nuclear Energy Programme'.

Staff – Assistant Technical Officer

Mr J. R. Partridge, B.Sc., has been appointed Assistant Technical Officer of the Institute. He is a graduate of Cambridge University and has had experience in the design side of industry, both in civil and mechanical engineering.

NEWS OF MEMBERS

Dr. **W. D. Biggs** has resigned from his appointment as leader of the Fundamental Research Section of the Research Department of Murex Welding Processes Ltd., to join the Engineering Department of the University of Cambridge.

Dr. **Nicol Gross**, Managing Director of Quasi-Arc Limited, and a former Assistant Director of the British Welding Research Association, was recently married in Switzerland to Mrs. **Eileen Haynes**, who was one of the first members of the staff of the Welding Research Council (now the B.W.R.A.).

The Council regret to announce the deaths of the following:

J. H. Laithwaite, Chairman and Managing Director of William Neill & Son (St. Helens) Ltd. (Associate Member 1946). Mr. A. E. W. Baines, who has for many years been Sales Director, is the new Chairman of the Company.

W. M. Howson of the South London Branch (Member 1943).

G. Wilson of Tyneside Branch (Member 1942).

W. H. Carslaw, B.Sc., Editor of Publications in Lloyd's Register of Shipping (Member 1943, North London Branch). Since 1954 Mr. Carslaw had been Chairman of the Membership Committee of the Institute.

Mr. **F. H. Keating**, Chief Metallurgist in the engineering research department of Imperial Chemical Industries Ltd. (Member of Council of B.W.R.A.).

CONTRIBUTORS TO THE JOURNAL

S. Astley, Chief Planning Engineer at John Thompson Motor Pressings Ltd. After commencing work at the age of 14, in the Wing and Panel Dept. of John Thompson, Mr. Astley went through the Production and Maintenance Depts. and became a toolmaker. In 1939 he was transferred to the toolroom of his present Company, as foreman responsible for tooling supplied to John Thompson Aero Components Ltd.

In 1945 he became Assistant Toolroom Superintendent, and in the following year he designed and put into commission a machine for automatically welding motor chassis side members.

Mr. Astley then was made tool estimator in 1947, and was responsible for the toolroom incentive scheme. He took up his present appointment in 1955.

Since the installation of the first automatic machine in 1946, Mr. Astley has designed and put into commission eight additional automatic chassis side member welding machines, the latest being the CO_2 machine described in the paper published in the September issue of the *Journal*.

J. E. Tomlinson, B.Sc., A.I.M., Research Metallurgist on the staff of the British Aluminium Co. Ltd. Mr. Tomlinson was born in 1923 and was educated at Manchester Grammar School. Upon graduation from the University of Manchester with an Honours degree in Metallurgy in 1943, he joined the Research Laboratories of his present Company.

Since 1949 Mr. Tomlinson has led the group concerned with the strength of materials, engineering research, and jointing methods.

R. V. Blewett, L.I.M., Welding Metallurgist on the staff of The British Aluminium Co. Ltd. He was born in 1929 and was educated at Dartford Grammar School. In 1946 he joined the Intelligence Dept. of the Company, and was later transferred to the Research Laboratories, where he was engaged on corrosion research.

During this period Mr. Blewett studied metallurgy at Battersea Polytechnic, and was elected a Licentiate of the Institution of Metallurgists in 1952. He then left to undergo National Service, and was commissioned in the Royal Engineers.

After leaving the Army Mr. Blewett returned to his previous position and studied problems of stress corrosion until March 1957, when he took up his present appointment. He is engaged on welding research and development, with special reference to automatic welding.

P. Shaw, M.A., Director of Quasi-Arc Limited, in charge of the Gateshead Works, where research, development, and production is concentrated on automatic welding machines and allied equipment. He was educated at Rugby and at Cambridge University, where he took an Honours degree in Mechanical Sciences.

After early industrial experience with the De Havilland Aircraft Co., where he worked on the stressing of aircraft, he joined the Ministry of Aircraft Production in 1940. He then became an Industrial Consultant and subsequently joined Fusarc Ltd. in 1954 as General Manager. On the amalgamation of the Company with Quasi-Arc Limited, Mr. Shaw became a member of the Board.

William A. Davis, Erection Engineer for the Chicago Bridge and Iron Co., the parent company of Chicago Bridge Ltd. of London. He was born in 1928 in Birmingham, Alabama, U.S.A., and is a graduate Civil

Engineer of the Renselaear Polytechnic Institute of New York. He joined Chicago Bridge in 1950.

Mr. Davis has taken an active part in the development work on the patented automatic girth welder, and pioneered the development of field stress relief of large site-erected pressure vessels. His current work is devoted to the development of new erection equipment and procedures.

BRITISH WELDING RESEARCH ASSOCIATION

Lectures

The first two of a series of lectures to be held in Dublin, under the auspices of the Irish Welding Association, were given on Monday and Tuesday, 22nd and 23rd September, at the Institution of Civil Engineers' Hall, Dolphin Street, Dublin.

The speakers were Dr. Richard Weck and Dr. A. A. Wells, respectively Director and Assistant Director of the B.W.R.A., and the meeting was opened by Mr. J. C. Costello, Secretary of the Irish Welding Association.

Mr. P. T. Houldcroft, Chief Metallurgist of the Research Association, will give a lecture to the staff of the Atomic Weapons Research Establishment at Aldermaston on 20th October, when he will describe the research programme of the B.W.R.A.

S. Astley

J. E. Tomlinson

R. V. Blewett

P. Shaw

Correction

The following correction should be made to the paper "*Why Weld Automatically?*" by I. C. Fitch (July 1958 issue of the *Journal*):

Page 306—formula in right-hand col. should read:

$$\text{Feed speed (in./min)} = \frac{0{\cdot}0022 \times \text{amp}}{(\text{elect. dia., in.})^2}$$

DIARY

1st Oct.—Manchester—*The Inert-Gas Welding Processes* by W. A. Woollcott (Manchester College of Science and Technology).

2nd Oct.—Eastern Counties—To be arranged (Colchester).

North Eastern (Tyneside)—Paper by R. R. Sillifant.

South Western—*The Welding of Stainless Steels* by W. K. B. Marshall (Radiant House, Bristol 1, 7.15 p.m.)

6th Oct.—West Wales—Film Show introduced by H. Webborn (Swansea Technical College).

7th Oct.—East Wales—Film Show (South Wales Institute of Engineers, Cardiff).

North London (Slough Section)—*Tests and Inspection of Welds* by R. B. Whalley (Community Centre, Slough, 7.30 p.m.)

8th Oct.—Leeds and District—*Welding in the Mining Industry* by S. C. Walker (Wakefield).

9th Oct.—South London—Forum: *Should the Institute of Welding Issue Certificates of Competence to Welders?* with F. Clark, F. Henry, J. L. Sanders, A. E. Swetman (54 Princes Gate, 7.30 p.m.)

Eastern Counties—*Resistance Welding* (Norwich).

13th Oct.—Manchester—*Welding as a Career for Adventure* by G. C. Musted (Bolton Technical College).

Sheffield and District—*Development in Gas-Shielded Processes for the Welding of Mild Steel* by D. B. Tait (Grand Hotel, Sheffield, 7.15 p.m.)

14th Oct.—East Midlands—*The Welding of High-Temperature and High-Pressure Pipe Work* by W. T. Roe (Welbeck Hotel, Nottingham, 7.15 p.m.)

Liverpool and District—*Selection and Uses of the Arc Welding Processes* by E. Flintham (Byrom Street).

15th Oct.—North Eastern (Tees-side)—Structural talk to be arranged.

West of Scotland—*Welding in the Rocket Industry* by F. J. Wilkinson.

Wolverhampton—*Chairman's Address* by M. R. Liddiatt (Holly Bush Hotel, Wolverhampton, 7.30 p.m.)

16th Oct.—Southern Counties—*The Welding of Plastics* by H. P. Zade.

22nd Oct.—East of Scotland—*Tungsten-Arc Cutting* by P. L. Beck.

South London (Medway Section)—*Weld Inspection* by D. T. Carter (Fredk. Braby & Co., Thames Road, Crayford, 7.30 p.m.)

23rd Oct.—Leeds and District—*Inside the Welding Arc* by J. F. Lancaster (Gt. Northern Hotel, Leeds, 7.30 p.m.)

28th Oct.—Institute of Welding, Institution of Mechanical Engineers, Aluminium Development Association, Institution of Chemical Engineers—*Symposium on Aluminium Pressure Vessels* (1 Birdcage Walk, S.W.1, 2.0 p.m.)

29th Oct.—North London—*Resistance Welding and Brazing in Large Quantity Light Engineering Production* by E. V. Beatson (54 Princes Gate, 7.30 p.m.)

3rd Nov.—West Wales—*Reclamation of Plant and Machinery* by G. C. Musted (Swansea Technical College).

4th Nov.—East Wales—*Reclamation of Heavy Plant and Machinery by Practical Welding Applications* by G. C. Musted (South Wales Institute of Engineers, Cardiff)

South Western—*The Welding of Tubular Structures* by G. B. Godfrey (Radiant House, Bristol 1, 7.15 p.m.)

5th Nov.—Manchester—*Residual Stresses; Do They Matter?* by L. E. Benson (Manchester College of Science and Technology).

6th Nov.—North Eastern (Tyneside)—*Non-destructive Examination of Welded Structures* by T. V. Brown.

CLASSIFIED ADVERTISEMENTS

Situations Vacant

WELDING RESEARCH AND DEVELOPMENT LABORATORY

A vacancy has arisen for

An Experienced Graduate Metallurgist

who is required for research and development work on problems associated with the weldability of a wide range of materials which may have applications in Steam, Gas and Water Turbines and Nuclear Reactors.

Applicants should have had at least three years' general metallurgical experience, and some knowledge of welding problems would be an advantage.

A vacancy also exists for

A Welding Engineer

to undertake development work on new welding processes and on the application of existing processes to the production welding of components used in Steam, Gas and Water Turbines and Nuclear Reactors.

Applicants should hold a degree or its equivalent and have had some experience in the problems outlined above.

Please write, giving details of education, qualifications and experience to Dept. C.P.S., 336/7 Strand, W.C.2, quoting Ref. WJ 1814K.

ENGLISH ELECTRIC

Chief Welding Engineer—£1,500–£2,000—to take charge of a Welding Department which advises on all aspects of welding for the Design Office and Works in Scotland and sites throughout Britain. This Department is already staffed but is being expanded (see below). Candidates must have an Engineering Degree or equivalent qualification. Sound practical experience, particularly of the effect of welding procedures and methods on quality and dimensional accuracy, is important.

Three Welding Engineers—£1,000–£1,500—to specify welding procedures, supervise welding tests, develop welding methods and equipment. Good practical experience is essential but academic attainments are also considered important, particularly for promotion prospects. The welding engineers will be based in Scotland.

The Company which has the above vacancies is in Scotland, where all successful applicants would be required to live. The Company is engaged in structural and heavy plate work of every variety and quality, including atomic energy work. Assistance will be given with removal expenses.

An industrial engineering consultant specializing in heavy engineering has been retained to advise on these appointments, and the names of applicants will not be disclosed to the Company concerned without the permission of the applicant. Please apply to Box 224.

Classified Advertisements—*continued*

WELDING ENGINEER

Metropolitan-Vickers Electrical Co. Ltd. require an **Assistant** to the **Welding Engineer** of their Steel Products Department.

Applications from young men between 23 and 30 years of age are invited for this vacancy. The necessary qualification is a degree or its equivalent in engineering and/or metallurgy.

Experience of modern welding processes and fabrication work—particularly automatic welding—would be an advantage, but such experience is not essential, as specialized training would be given to the successful applicant.

Applications, quoting reference Y. 11 should be made to:

Personnel Manager
Metropolitan-Vickers Electrical Co. Ltd.
Trafford Park
Manchester 17

Leading Design and **Detail Draughtsman** wanted for industrial tankwork, including pressure vessels, hoppers, stainless steel, and stainless clad tanks and outside storage tanks, and with knowledge of British and American specifications.

Apply stating experience and salary required to The Directors, John Booth & Sons (Bolton) Ltd., Hulton Steelworks, Bolton.

English Electric have vacancies in their Welding Equipment Section for young **Metallurgical** and **Electrical Engineers** interested in Arc Welding Equipment and Electrodes, and in the application of this equipment to welding and fabrication techniques.

These appointments are pensionable after a qualifying period. Engineers who feel they already possess the necessary experience and others who have basic training and a desire to broaden their experience are asked to communicate with C.P.S., 366/7 Strand, W.C.2, quoting reference WJ 414F.

Welding Supervisors required for work on Nuclear Power Stations; must be experienced in the positional welding of Class I pressure vessels, all welding subject to radiograph examination. Applicants must have experience of welding in this field, and knowledge of non-destructive methods of testing. Positions are staff appointments; only experienced men need apply.

Applications in writing to the Personnel Manager, John Thompson Limited, Wolverhampton.

COST INVESTIGATION ENGINEER

An engineer is required for cost investigation work in the Steel Products Department which manufactures a wide range of welded steel fabrications. A degree or equivalent qualification in mechanical or electrical engineering is desirable; some knowledge of cost accounting would be an advantage. Age range 25 to 40. Salary according to qualifications and experience.

Write for application form, quoting reference Z.11 to:

Personnel Manager
Metropolitan-Vickers Electrical Co., Ltd.
Trafford Park
Manchester 17

Fitter Machinist – Civilian Instructional Officer required at H.M. Prison, Leeds. Age at least 30 on 29th October 1958. Qualifications: Full apprenticeship plus at least 5 years practical experience of processes involved in the manufacture of tubular and fabricated sheet furniture for prisons. A knowledge of jigs and fixtures used would be an advantage, and a City and Guilds certificate or equivalent in Engineering Fitting is desirable.

Salary £771 to £895. 44 hour 5½ day week. Generous paid holidays. Quarters not provided. Pensionable appointment considered after a period of satisfactory service.

Write Prison Commission, R.241/196, Horseferry House, Dean Ryle Street, London S.W.1.

Current WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

THIS SECTION is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the *Bibliographical Bulletin of Welding and Allied Processes*, published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.

Welding Journals

Welding and Metal Fabrication, 1958, vol. 26, July

Heat exchangers for nuclear power (234–238)

The welding of lead (239)

Oil drilling platform construction. Fabricating a 4,800 ton off-shore structure at Southampton, T. J. Palmer (240–248)

Assessment of an electronic image-intensifier for weld radiography, R. Halmshaw (249–255)

Temperature controller for heat-treatment of pipe welds, D. Birchon (256–258)

Sounding brass (259–265 to be concluded)

Welding Journal (U.S.A.), 1958, vol. 37, June

Engineering problems of an all-welded two-way truss system, Wayne Teng, John A. Sbarounis and Michael P. Gaus (565–569)

Spot welding of Inconel "X" in thickness range of 0·032 to 0·188 in., Jean Harris, M. D. Bellware and J. J. Riley (570–578)

Elements of joint design for welding, K. H. Koopman (579–588)

Porosity in aluminium-alloy welds, F. R. Collins (589–593)

Wide-span arches for rigid-frame school structure are completely arc welded, William F. Fischer (594–596)

Tungsten-arc welding raises output of aluminium window frames (596)

Welding builds "transportation casks" for radioactive materials, P. E. Woodward (579)

Electrode-tip life studies in series spot welding, E. F. Nippes, W. F. Savage, S. M. Robelotto and K. E. Dorschu (241*s*–248*s*)

Bonding of cement-valve components to metals, G. M. Slaughter P. Patriarca and W. D. Manly (294s–254s)

The arc welding of wrought magnesium-thorium alloys, L. F. Lockwood and Paul Klain (255s–264s)

Today's trend in ship research, David F. Felbeck (265s–268s)

Chlorine additions for high-quality inert-gas metal-arc welding of aluminium alloys, M. B. Kasen and A. R. Pfluger (269s–276s)

Reinforcement of openings in pressure vessels, E. O. Waters (277s–288s)

Soudage et techniques connexes (France), 1958, vol. 12, May–June

Vacuum welding of metals, J. A. Stohr and J. Briola (165–172)

On the properties and the fatigue strength of a metallized copper surface, J. Salokangas and P. Lehto (173–181)

Schweisstechnik (Austria), 1958, vol. 12, June

Welding of pressure-vessel steels in heavy sections by the electro-slag process, W. Anders (65-70)

Welding of alloy steels without preheating in the chemical industry, Werner Gilde (84–87)

Automatic submerged-arc welding of thin plates, H. Buszka (87–91)

Werkstatt und Betrieb (Germany), 1958, vol. 91, June

Experiences gained in argon-shielded Sigma hard facing and in carbon-dioxide joint welds, R. Nass and E. Brammertz (297–305)

Ultrasonic welding, W. Weber (305–310)

New knowledge about the influence of hydrogen upon steels and their welds, K. L. Zeyen (310–320)

Journal of the Japan Welding Society, 1958, vol. 27, May

A metallurgical study on the weld heat-affected zone of steel with a reproducing apparatus of weld thermal cycles (report 3), H. Suzuki, H. Tamura, Y. Kawana and R. Hashiguchi (2–8)

On the recovery of the notch toughness of strain-aged steels, S. Morita and S. Goda (9–14)

Thermal efficiency of oxy-acetylene flame (Report 2), I. Onishi, M. Mizuno, H. Hori and I. Koshizawa (15–19)

A study on the electrochemical potential of arc welds, K. Matsuo, S. Yamajo and S. Adachi (20–23)

Resistance Welding of heat-resisting alloys, Y. Yamazaki and K. Wada (24–33)

On the causes of the self-regulating characteristics of Mig welding, K. Ando and J. Nishikawa (34–37)

Study of melting speed of electrodes, K. Ando, F. Ueyama and T. Manki (38–43)

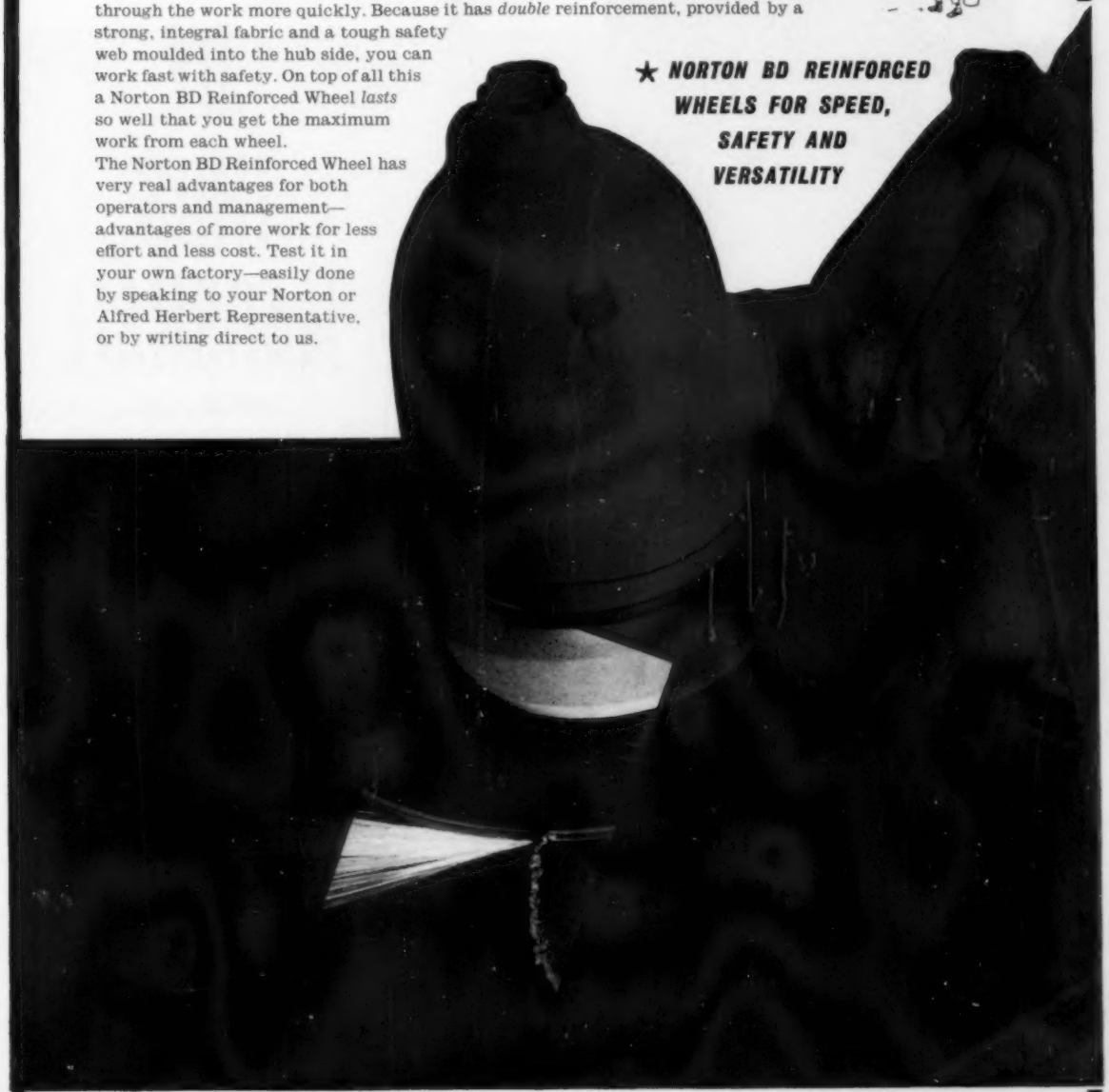
The "All-rounder!"

Norton BD Reinforced Wheels will do a multitude of jobs in the metal fabricating shop. Cleaning up and bevelling, cutting down and smoothing weld beads, slotting and cutting off, roughing and finishing—you can do it all quickly, cleanly, safely and economically with a Norton BD wheel.

Because it cuts fast and cleanly without spalling or loading the Norton BD wheel gets through the work more quickly. Because it has *double* reinforcement, provided by a strong, integral fabric and a tough safety web moulded into the hub side, you can work fast with safety. On top of all this a Norton BD Reinforced Wheel *lasts* so well that you get the maximum work from each wheel.

The Norton BD Reinforced Wheel has very real advantages for both operators and management—advantages of more work for less effort and less cost. Test it in your own factory—easily done by speaking to your Norton or Alfred Herbert Representative, or by writing direct to us.

★ ***NORTON BD REINFORCED WHEELS FOR SPEED, SAFETY AND VERSATILITY***



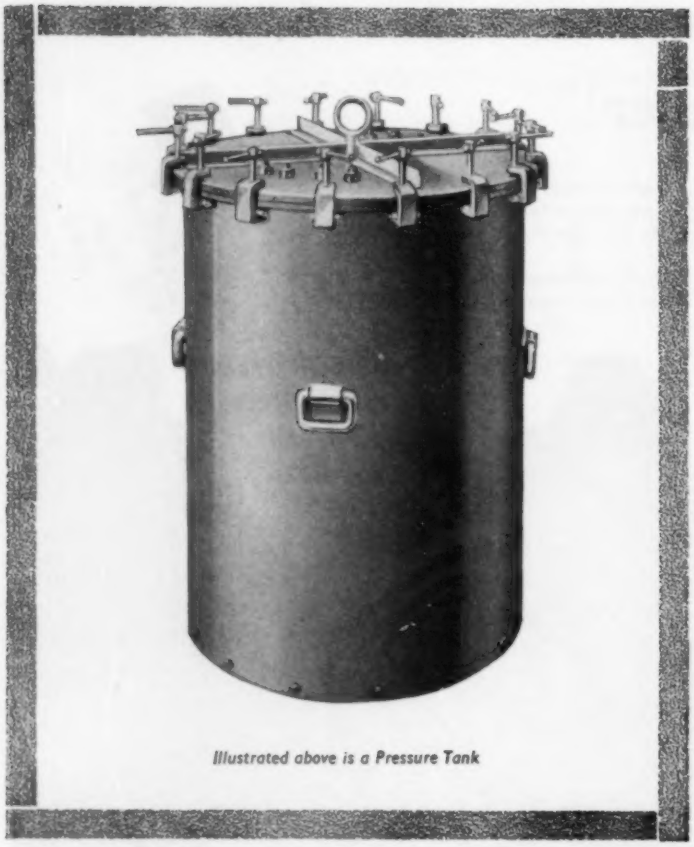
NORTON GRINDING WHEEL CO. LTD. **NORTON ABRASIVES**

WELWYN GARDEN CITY, HERTS. Telephone: WELWYN GARDEN 4501 (10 lines)

Enquiries also to: **ALFRED HERBERT LTD., COVENTRY**

NORTON and BEHR-MANNING *factories also in Argentina, Australia, Brazil, Canada, France, Germany, Italy, Northern Ireland, South Africa and U.S.A.*

NGW/BD/136



Illustrated above is a Pressure Tank

STEEL FABRICATIONS BY THOS. MARSHALL

AND SON LTD.

THOS. MARSHALL & SON LTD
WELLINGTON BRIDGE, LEEDS, 12
Telephone: 32186 (5 lines) Grams: 'Cisterns' Leeds 12

To Photographic and Radiological Departments:

A new PURHYPO Silver Recovery Unit

PURHYPO – for many years recognised as the simplest method of regeneration of the photographic fixer and recovery of silver – now comprises a new and simpler equipment.

Just fix the rectifier unit on a wall conveniently near the fixing tank, and suspend the electrode assembly in your tank. If fixing space is too small, the electrodes can be fitted after working hours, or in a separate reserve tank to which exhausted hypo is transferred for regeneration.

The deposit on the stainless steel strips of the cathode can be easily removed in the form of flakes of pure metallic silver.

Recovers the silver. Saves fixer. Improves fixing time

- **no moving parts**
- **no risk of frothing**
- **negligible current consumption**

Sole Agents for British Commonwealth:

D. PENNELLIER & COMPANY LIMITED

28 HATTON GARDEN, LONDON, E.C.1

Telephone: HOLborn 4064 CHAncery 4681/2

The new RAYMAX 50

–for 'soft' radiation

Radiograph of one pound note.

The Raymax 50—tube-head, bench - mounting stand and control unit.

With the Raymax 50, Newton Victor have evolved an x-ray unit capable of producing 'soft' radiation so that minute changes in the density of a specimen are clearly shown. The fine focus, producing sharply defined high contrast images, makes the unit ideal for the examination of spot welded joints in thin sheets, forged documents, portraits, postage stamps and micro radiography.

The equipment consists of a transformer, tube-head and control box. The tubehead, which includes an H.V. transformer and a filament transformer, is fitted with an x-ray tube having a beryllium window; the complete assembly is mounted in an oil-filled container. The control unit includes a kilovoltmeter and continuously variable kilovoltage control.

For further information please write for publication No. ES4175/51.

Newton Victor Ltd

132 LONG ACRE · LONDON · WC2

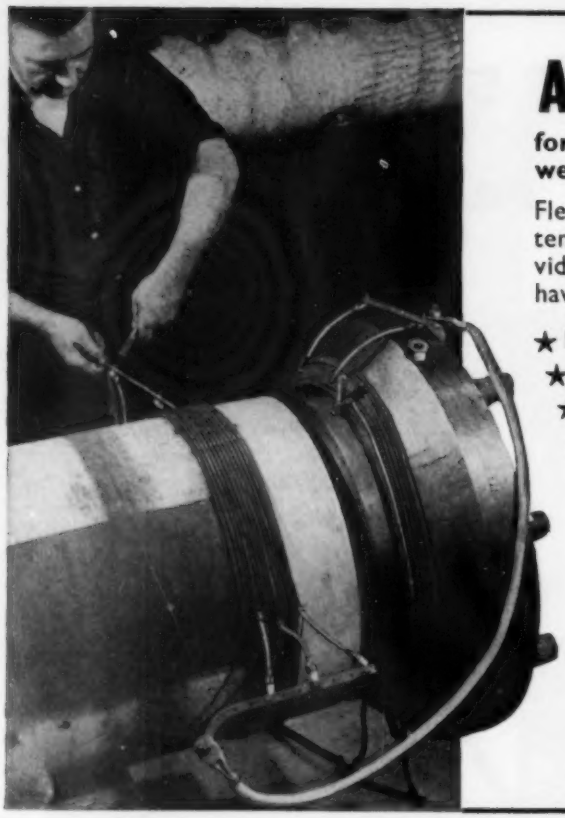
x-ray sales department of

METROPOLITAN-VICKERS

ELECTRICAL CO LTD · TRAFFORD PARK · MANCHESTER, 17

An A.E.I. Company

X/V709



ARMOURED HEATERS

for the pre-heating and stress-relieving of welds and other forms of heat treatment.

Flexible resistance heaters to operate at working temperatures up to 800°C (1472°F) readily provide heat treatment to code requirements and have many advantages over other methods:

★ LOW INITIAL COST ★ LOW POWER CONSUMPTION
★ EASILY INSTALLED ★ EASILY CONTROLLED
★ SAFE LOW VOLTAGE ★ PORTABLE

Illustration shows typical set-up being prepared for heat treatment and welding
(photo by courtesy of Foster Wheeler Ltd.)

Please write for the new illustrated leaflet No. W/321

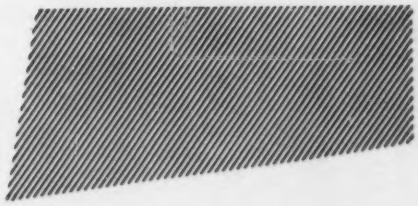
ELECTROTHERMAL ENGINEERING LTD

270 Neville Road, London, E.7 Tel. GRA 9911

FOR OXY-ACETYLENE AND ELECTRIC ARC WELDING

RYLANDS Brothers Limited Warrington

MANUFACTURERS OF STEEL WIRES FOR ALL PURPOSES

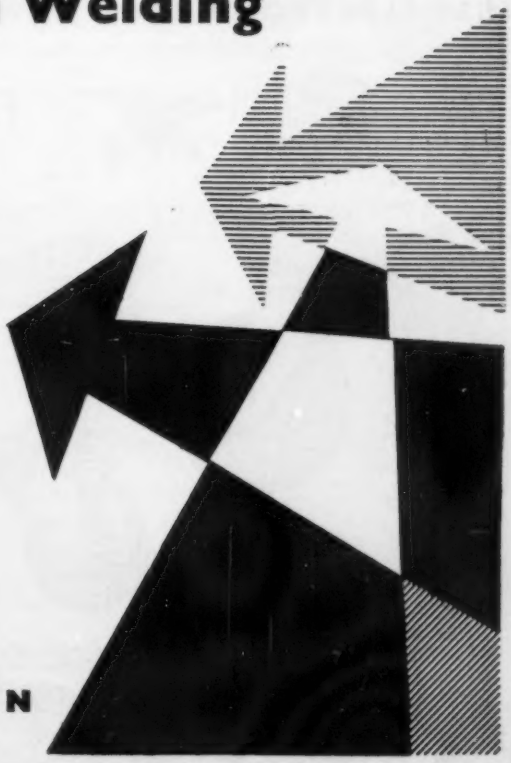


To progress, Industry needs to apply the latest technical know-how. In no technology is this more true than in that of welding. To meet this need the British Welding Research Association has prepared a large number of booklets dealing with many aspects of welding – from design to inspection.

Information on Welding

for

- Shop floor
- Drawing office
- Production planning
- Colleges of Engineering and Technology



please write for further information to Publications Officer of the

BRITISH WELDING RESEARCH ASSOCIATION

29 Park Crescent, London, W.1

HAND WELDING TONGS AND POWER UNIT

H.E.D

These precision hand welding tongs have been designed to overcome the problem of difficult placed welds. They have a built-in micro-switch and adjustable electrode pressure and initiation is by low voltage making the tongs safe from shock. For existing equipment without low voltage switching a small adaptor unit is available.

The power unit illustrated is housed in a robust steel case and consists of a power transformer, electro-mechanical timer and current control resistance. Voltage 200/240 A.C. Illustrated leaflet available on request.

Available in two sizes
WTA for max. welding wire dia. .125 combined
WTB for max. welding wire dia. .187 combined

OTHER H.E.D. PRODUCTS ✱ *Coil Winding* ✱ *Welding Control* ✱ *High Speed Contactors* ✱ *Saturable Reactors* ✱ *Transformers* ✱ *Precision Welding Equipment* ✱ *Magnetizing Equipment* ✱ *Air-conditioned Welding and Assembly Benches*

HIRST ELECTRONIC LTD · GATWICK ROAD, CRAWLEY, SUSSEX · CRAWLEY 25721-2-3

For increased efficiency . . . .

Flexello
put it on Castors

'Putting it on castors' is certainly the way to speed things up, and to an amazing extent when the right castors are used for the job. The varied uses of Flexello castors are virtually limitless. They are used in nurseries and steel mills, aircraft plants and beauty parlours. Flexello has the range, the service and facilities to make castors the true servant of the production manager, the hospital matron, the restaurant manager or the storekeeper. Closest inspection, superior design and up-to-date production methods have made Flexello the largest castor manufacturer in Europe.

Flexello

CONSTANT QUALITY
CASTORS

Only a very small section of our range is shown here. Please send for catalogue No. 156 B.W.J. or a technical representative for industrial advice.

FLEXELLO CASTORS & WHEELS Ltd. SLOUGH, BUCKS. Tel. Slough 24121

B T-H IGNITRONS

British Thomson-Houston manufacture the widest range of ignitrons in the United Kingdom—moreover all BTH ignitrons are interchangeable with the corresponding American types. Whatever the job, from the BTH lists you can select the *right* valve.

Write for Leaflet 5851-8

BTH ELECTRONICS DATA SHEET
Subject IGNITRONS — RATINGS

Welder types

Types	Maximum Demand* (kVA)	Maximum average* anode current (Amps.)	Temperature control
BK 22	450	15	—
BK 24	1200	140	—
BK 24A	1200	140	Integral
BK 24B	1200	140	Clamp on
BK 34	2400	355	—
BK 34A	2400	355	Integral
BK 34B	2400	355	Clamp on
BK 42	600	56	—
BK 42A	600	56	Integral
BK 42B	600	56	Clamp on
BK 66	300	22·4	—

* Ratings are for welder control service and refer to two valves in inverse parallel at any voltage from 250-600v. r.m.s.

Rectifier types

Type	Maximum peak voltage (Kilo volts)	Maximum average current at peak voltage (Amps.)
BK 44	2·1	75
BK 46	2·1	150
BK 56 †	20·1	150

† Tentative ratings.

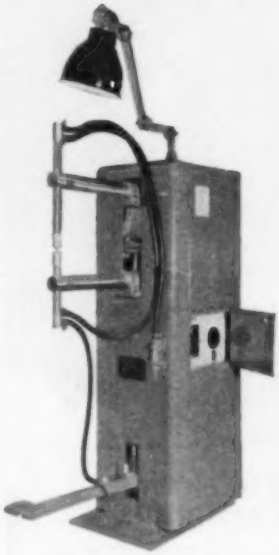
BRITISH THOMSON-HOUSTON

THE BRITISH THOMSON-HOUSTON COMPANY LIMITED · LINCOLN · ENGLAND

an A.E.I. Company

A 5192

RESISTANCE WELDING MACHINES



Meritus Pedestal Type Spot Welding Machine

SERVING

THE

NUCLEAR POWER, AIRCRAFT AND ENGINEERING INDUSTRIES

IF YOU REQUIRE RESISTANCE WELDING PLANT

CONSULT

MERITUS

FIRST

Write for details:

MERITUS (BARNET) LTD.

BARNET, HERTS.

TELEPHONE: BARNET 2291/2

ADVERTISERS' INDEX

Anglo-Swedish Electric Welding Co.	16
B.I.X. Ltd.	Inside front cover
Babcock & Wilcox Ltd.	—
Barnes, Douglas, Ltd.	18
Booth, John, & Sons Ltd.	—
Braithwaite & Co. (Engineers) Ltd.	—
British Industrial Gases Ltd.	15
British Insulated Callender's Cables, Ltd.	—
British Oxygen Gases Ltd. Outside back cover.	19
British Thomson-Houston Co. Ltd.	31
Butterfield, W. P., Ltd.	—
Carborundum Co. Ltd., The	—
Cooper & Turner Ltd.	2
Courtburn Positioners Ltd.	5
Crompton Parkinson Ltd.	—
Distillers Co. Ltd., The	9
Dorman Long (Steel) Ltd.	—
Electrothermal Engineering Ltd.	28
English Electric Co. Ltd., The	14
Eutectic Welding Alloys Co. Ltd.	8
Flexello Castors & Wheels Ltd.	30
General Electric Co. Ltd., The	4
Hancock & Co. (Engineers) Ltd.	17
Harvey, G. A., & Co. (London) Ltd.	1
Hirst Electronic Ltd.	30
Ilford, Ltd.	13
Imperial Chemical Industries, Ltd.	6
Invicta Electrodes, Ltd.	—
Jenkins, Robert, & Co. Ltd.	—
Johnson, Matthey & Co. Ltd.	3
Johnson, Richard, & Nephew, Ltd.	—
Kodak Ltd.	10
Lincoln Electric Co. Ltd.	22
Marconi Instruments Ltd.	—
Marshall, Thomas, & Son, Ltd.	26
Marston Excelsior Ltd.	—
Meritus (Barnet) Ltd.	32
Mersey Cable Works Ltd.	—
Metal and Pipeline Endurance Ltd.	—
Metropolitan-Vickers Electrical Co. Ltd.	24, 27
Milne, C. S., & Co. Ltd.	—
Morris, B. O., Ltd.	—
Murex Welding Processes, Ltd.	—
Newton Victor Ltd.	27
Norton Grinding Wheel Co.	25
Pennellier, D., & Co. Ltd.	26
Philips Electrical, Ltd.	Inside back cover
Quasi-Arc Ltd.,	11
Robey & Co. Ltd.	18
Rockweld, Ltd.	—
Rylands Bros., Ltd.	28
Saturn Industrial Gases Ltd.	12
Smith, Hugh, & Co. (Possil) Ltd.	7
Spencer Wire Co. Ltd., The	—
Suffolk Iron Foundry Ltd.	16
Wiggin, Henry, & Co. Ltd.	20

Published by THE INSTITUTE OF WELDING, 54 Princes Gate, London, S.W.7
Made and printed by Percy Lund, Humphries & Co. Ltd., London and Bradford

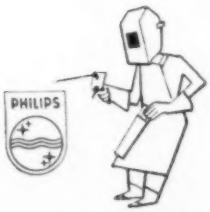
FASTER WORK ! 50% to 100% faster than with normal mild steel electrodes. Easier, too ! Slag *lifts* off, eliminating usual chipping and brushing.

BETTER WORK ! Leaves a smooth even weld with perfect surface finish, and excellent mechanical strength.

Photograph of welded wagon door by courtesy of Metropolitan-Cammell Carriage & Wagon Co. Ltd., Saltley, Birmingham.

AT LESS COST ! Saves all the way—means more output, and a better job all round. Reduces work before finishing to a minimum.

PHILIPS C23 IRON POWDER ELECTRODE



Philips Electrical Ltd
Industrial Products Division
Century House · Shaftesbury Avenue
London · WC2

The C23 electrode is specially designed for very fast welds in the downhand, standing fillet, and horizontal-vertical positions.

Immediate striking and re-striking of the arc. Flexible length of deposit; e.g. a standing fillet can be made with one electrode within the range 10"–30" in length at the same current setting.

Chief characteristics of the electrode are :

High rate of metal deposition.
Extremely easy slag removal.
Ease of welding.
Excellent weld appearance at all speeds.
Suitable for COR-TEN Steel.
Less sensitive to plate impurities than normal mild steel electrodes.
B.S.1719 : 1951 code No. E 927.
The type C23 may be used on either A.C. or D.C.

(P10277)

Inside back cover

FROM BRITISH OXYGEN — FOR BRITISH INDUSTRY

Always ask for

"ALDA"

rods and fluxes

BRITISH OXYGEN SUPPLY ALDA

—the famous range of rods
and fluxes. And a complete range
of welding accessories—
from goggles and gloves
to friction lighters and wire brushes.
ALWAYS ASK FOR ALDA.
Write for fully illustrated literature.

BRITISH OXYGEN

British Oxygen Gases Ltd., Industrial Division, Spencer House, 27 St James's Place, London, S.W.1.

Outside back cover